Coupling Behavior of the Thoracic Spine: A Systematic Review of the Literature

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Abstract

Objective: The knowledge of 3-dimensional spine coupling characteristics is important for treating patients with spinal pain. The purpose of this study was to examine the coupling directional pattern of the thoracic spine by systematic review. This review could help determine the use of coupling knowledge for manual therapy treatment.

Methods: A systematic review of studies examining in vivo and in vitro thoracic spine coupled motion was conducted using PubMed and Cumulative Index to Nursing and Allied Health Literature searches (1960-2006), as well as a separate hand-search. Study abstracts were independently reviewed and selected by two investigators based on face validity. The reliability between investigators was established using the Kappa (K) coefficient. A third investigator resolved any inclusion disagreement. Full studies were then evaluated for compliance with inclusion criteria. Coupling patterns from accepted studies were then qualitatively compared.

Results: Of the 56 citations originally identified in the searches, the first two investigators reached consensus on 41 citations and required further assistance by the third investigator on 15 citations. The reliability between investigators was rated fair ($K = 0.38$). Twenty-one citations were deemed acceptable for further review. Of 21 citations, 8 met the inclusion criteria and were fully reviewed. No consistent coupling pattern was observed across the 8 studies, where they exhibited ipsilateral, contralateral, or mixed coupling behaviors.

Conclusions: Differences in study design, measurement method, and tissue preparation may have contributed to differences between studies. More quality, in vivo investigations are needed to evaluate thoracic coupling in symptomatic subjects in both a flexed and extended position. (J Manipulative Physiol Ther 2007;30:390-399)

Key Indexing Terms: *Biomechanics; Movement; Spinal Manipulation; Thoracic Vertebrae*

The thoracic spine is considered a transitional zone between the cervical and lumbar spine, yet is unique because of the size and extent of the region and the articulations with the rib cage. The articulations with the rib cage lead to regional variations in movement patterns and function.[1] The combined flexion and extension range of motion in the thoracic spine is bimodal, from the superior to the inferior segments.[2] The upper thoracic spine shows a total of 3° to 5° of flexion or extension that is reduced to 2° to 7° at T5 to T6 and further increases to 6° to 20° at T12 to L1. Overall, greater range of motion is available in flexion than in extension.[2]

Several anatomical components control or contribute to the available movements of the thoracic spine. The intervertebral disk plays a major role in movement control of the thoracic spine, a much more significant role than the posterior structures.[3] With respect to height, the disk in the thoracic spine shows less height in ratio to the vertebral body than the cervical and lumbar spines.[4] In addition, the thoracic disk has a relatively small nucleus pulposus.[5] There are variations in the orientation of the zygapophyseal joints (facets) throughout the length of the thoracic spine. In general, the superior facets face anteriorly but are not completely aligned in the frontal plane.[6] This angulation is reduced as the thoracic spine descends, culminating at T12. At T12, the facets show an orientation similar to lumbar spine facet orientation.[6]

Movement analysis is considered an essential element of clinical examination, including the biomechanical assessment of multiple planes of movement.[1] Germane to the

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Paper submitted December 1, 2006; in revised form February 23, 2007; accepted February 25, 2007.

0161-4754/$32.00

doi:10.1016/j.jmpt.2007.04.009

Table 1. *Search strategy to identify thoracic spine coupling manuscripts*

No.	Search history	Results[a]
1	Thoracic vertebrae/ or thoracic spine.mp.	12,151
2	Limit 1 to English language	9,516
3	Biomechanics.mp. or Biomechanics/	50,089
4	Limit 3 to English language	42,854
5	Coupling.mp.	52,580
6	Limit 5 to English language	50,650
7	Models, structural/ or three-dimensional.mp.	80,219
8	Limit 7 to English language	74,069
9	Movement.mp. or Movement/	174,798
10	Limit 9 to English language	155,707
11	2 and 4	610
12	8 and 10	3,780
13	6 or 12	54,348
14	11 and 13	22

[a] Numbers of citations produced by search.

Table 2. *Reasons for abstract rejection during the initial citation and abstract review*

Reasons for abstract rejection	No. of citations in this category
Examination of intermuscular coupling during a lifting task	1
Examination of limb coupling in spinal cord lesions	1
Evaluation of 3-D surface anatomy of thoracic vertebrae	1
A pure 3-D geometric structural reconstruction	1
Influence of spine morphology on intervertebral disk loads	1
The consequences of anatomical variation on thoracic kyphosis	1
Assessment of spine structural attributes	1
Motion analysis after selective cutting	2
Relationship of leg-length discrepancy and lateral bending motion during gait	2
Influence of lifting on spine mechanics	1
Response to posteroanterior loads applied to the spinous processes	1
General spinal flexibility measure	1
Examination of the effects of the rib cage on thoracic spine flexibility	1
Assessment of motion limited to pure segmental axial rotation	1
Motion assessment limited to thoracic cage translations	2
Assessment of rib mechanics	2
Evaluation of scoliosis development and progression	6
Modeling study of scoliotic deformities	1
Evaluation of the influence of scoliosis on segmental motion	1
Assessment was limited to lumbar coupling	3
Assessment was limited to cervical coupling	1
Paper was a commentary	1
No abstract available	2
Total	35

concept of biomechanical movements is spinal coupling biomechanics. By definition, coupling biomechanics, or coupled motion, is the rotation or translation of a vertebral body about or along one axis that is consistently associated with the main rotation or translation about another axis.[7] During movement, translation occurs when movement is such that all particles in the body at a given time have the same direction of motion relative to a fixed coordinate system.[7] With movement, rotation occurs as a spinning or angular displacement of the vertebral body around a particular axis of rotation.

Biomechanical coupling is 3-dimensional (3-D) and takes place within 6 degrees of freedom, where the vertebrae can translate along or rotate about each orthogonal axis.[7] The 3-D motions in human vertebral segments correspond to flexion/extension, rotation and side-bending (lateral flexion) forces; one specific movement initiation (such as side-bending) theoretically activates movement in the other component motions. This coupling behavior is dependent on the first motion of initiation (ie, side-bending), the posture of the spine, and the pathology of the segment.[8] Because the movements are 3-D, measurement should incorporate appropriate devices that address the multidimensional nature of movement. Failure in the use of the appropriate measurement device may lead to errors and inaccuracies associated with coupling biomechanics.

In theory, measurement of coupling motion is useful to diagnose pathological disorders, such as clinical instability due to degeneration, disease, or trauma.[9,10] It has been suggested that an advanced understanding of spine coupling biomechanics and kinesiology will result in better comprehension of symptoms manifestation and pathogenesis of spinal dysfunction.[11-16] If pathological coupling patterns exist, manual therapy practitioners could logically intervene and appropriately incorporate those movements to improve patient outcomes.

The purpose of this study was to review the coupling directional pattern of the thoracic spine by systematic examination of the literature. Examining the consistency among biomechanical investigations of thoracic coupling will help determine the utility of its use in manual examination and treatment of the spine. Within clinical practice, the side-bend and axial rotation initiations of movement are used more frequently than flexion/extension initiation. Because of the clinical relevance and the lack of representation in the literature of flexion/extension initiation, only coupling studies associated with initiation of side-bend and/or axial rotation initiation are investigated within this review.

Methods

Language

Studies written in the English language were reviewed.

Table 3. *Description of included studies, including specimen, number of subjects/specimens, status of surrounding tissues, and method for acquiring data*

Author	Specimen	N	Age (y)	Tissue preparation (if applicable)	Ribs and costal joints	Data acquisition method
Panjabi, 1976[18]	In vitro human	2 females and 3 males	19-59	Fresh frozen; disk, ligaments, and joints intact. All nonligamentous tissue removed from the segment	Ribs in place and CTJ and CVJ intact	Load cell measures acted upon rigid arms attached to the cranial vertebra
Oxland et al, 1992[19]	In vitro human	5 females and 3 males	19-70	Fresh frozen; all nonligamentous tissue removed from the segment	Ribs, CTJs, and CVJs dissected	Stereoradiophotogrammetric motion recording
Willems et al, 1996[1]	In vivo human	30 females and 30 males	18-24	All tissues intact	Ribs in place and CTJ and CVJ intact	3-Space Fastrak System
Gregersen and Lucas, 1967[20]	In vivo human	7 males	20-26	Steinmann pins embedded into the spinous processes	Ribs in place and CTJ and CVJ intact	Pin displacement was transmitted through a flexible extension arm to a relative rotation transducer
Stewart et al, 1995[21]	In vivo human	20 females	18-22	All tissues intact	Ribs in place and CTJ and CVJ intact	3-Space Fastrak System
Theodoridis and Ruston, 2002[22]	In vivo human	25 females	45-64	All tissues intact	Ribs in place and CTJ and CVJ intact	Electromagnetic Tracking System
Schultz et al, 1973[23]	Mathematical model	NR	NR	Disk, ligaments, and transverse processes were represented in the model	Ribs not represented	Mathematical model with computer program analysis
Scholten and Veldhuizen, 1985[24]	Mathematical model	NA	NA	Disk, ligaments, and transverse processes were represented in the model	Ribs not represented	Mathematical model with computer program analysis

CTJ, costotransverse joint; *CVJ*, costovertebral joint; *NR*, not reported; *NA*, not applicable.

Inclusion Criteria

Studies that investigated in vivo (live subjects), in vitro (cadaveric specimens), or modeled (mathematical modeling) thoracic spine coupled motion were selected. For inclusion, each study required an experimental analysis for detection of 3-D coupled movements. A report of coupled movement direction was required for inclusion. In addition, the investigators observed for a report of side-bend initiation or rotation initiation when evaluating the coupled movements. The analysis did not consider textbook references that referred to thoracic spine coupling because the likelihood that the reported thoracic coupling patterns were established through experimental measures was questionable.

Search Strategy for Selection of Studies

The present study selection strategy was initiated through the computer-based search engines of PubMed and Cumulative Index to Nursing and Allied Health Literature (February 1965-November 2006). The search strategy is outlined in Table 1. Each search included the search terms of "thoracic vertebrae or thoracic spine," "biomechanics," "coupling," "three-dimensional" or "models, structural," and "movement." Furthermore, a comprehensive hand-search of all articles references from those studies collected in the computer-based search and those known to the authors was conducted.

Methods of Review

Study abstracts were independently reviewed, and citations were selected by two authors (P. S. and C. C.) based on face validity. A binary decision (yes vs no) was used to determine if each citation was suitable for inclusion based on the study's apparent compliance with the previously discussed inclusion criteria. Investigators' preliminary decisions regarding the suitability for each study's inclusion were compared, and the reliability between investigators was established using the Kappa (K) coefficient. Citations that reached consensus between investigators were deemed suitable for inclusion and further review. For those citations where the two investigators disagreed, a third investigator (J. M. B.) reviewed the abstracts for suitability, thus making a tie-breaking decision for those specific citations. Once deemed suitable, the full text of each study was further evaluated to determine if the study, in fact, met the inclusion criteria and could be included as a part of the systematic review. Once included,

Table 4. *Composite quality scoring for study compliance with quality standards*

Quality standard	Study								Total no. of studies complying with a standard			
	Panjabi, 1976[18]	Oxland et al, 1992[19]	Willems et al, 1996[1]	Gregersen and Lucas, 1967[20]	Stewart et al, 1995[21]	Theodoridis and Ruston, 2002[22]	Schultz et al, 1973[23]	Scholten and Veldhuizen, 1985[24]	Y totals	N totals	NA totals	Percentage of studies complying with standards
Specimens												
1. Study specimens or subject pathology or status is adequately described	Y	N	Y	Y	Y	Y	NA	NA	5	1	2	62.5
2. Study specimen or subject preparation is adequate	Y	Y	Y	Y	Y	Y	NA	NA	6	0	2	75.0
3. Study performed with intact articular tissue (ligaments, capsule, cartilage, disk)	Y	Y	Y	Y	Y	Y	Y(1)	Y(1)	8	0	0	100.0
4. Study performed with intact adjacent soft tissue (muscle, tendon, fascia)	N	N	Y	Y	Y	Y	N(2)	N(2)	4	4	0	50.0
5. Study is performed without rib structures intact (rib, CVJ, CTJ)	Y	N	Y	Y	Y	Y	N(2)	N(2)	5	3	0	62.5
Methods												
6. Setup is adequately described and reproducible	Y	Y	Y	Y	Y	Y	Y	Y	8	0	0	100.0
7. Study identifies the use of 3-D measures of assessment	Y	Y	Y	Y	Y	Y	Y	Y	8	0	0	100.0
8. Study identifies single spinal level of assessment (not multiple levels)	Y	Y	N	Y	N	Y	Y	Y	6	2	0	75.0
9. Study outlines movement initiation for each measure	Y	Y	Y	Y	Y	Y	Y	Y	8	0	0	100.0
10. Study defines a “directional coupling pattern” using the Cartesian system	Y	Y	Y	Y	Y	Y	Y	Y	8	0	0	100.0
Analysis												
11. Data variance is reported (eg, SD or SEM)	N	Y	Y	N	Y	Y	N	N	4	4	0	50.0
12. Reliability measures are reported when appropriate	N	N	N	N	Y	Y	N	N	2	6	0	25.0
13. Experimental error is reported	N	N	Y	Y	Y	Y	N	N	4	4	0	50.0
14. Study reported instrumentation errors lower than the actual movement measured	N	NA	Y	Y	Y	Y	N	N	4	3	1	50.0
Application												
15. Reported movements are reproducible as clinically important values	N	Y	Y	Y	Y	Y	N	N	5	3	0	62.5
16. Study outlines limitations on experimental design	Y	Y	Y	Y	Y	Y	Y	Y	8	0	0	100.0
Yes grand totals (out of a total of 16 standards)	10	10	14	14	15	16	7	7				
Composite quality score (% of total)	62.5	62.5	87.5	87.5	93.8	100	43.8	43.8				

Y indicates no; Y, yes; NA, not applicable.
(1) Computer model did not include joint capsule.
(2) Computer model did not include these tissues.

the reported coupling behaviors of the thoracic spine from each study were qualitatively evaluated and compared.

To further analyze the quality of each study, the investigators methodologically scored each of the 8 articles reviewed. This analysis was based on 16 quality standards that described the quality of the specimens or subjects, the specifics regarding methodology, the analysis that was incorporated, and the clinical application of the findings. The investigators established the percentage of studies that complied with each quality standard. Moreover, a Composite Quality Score was established for each study reflecting the study's compliance with the quality standards. This score reflected the total number of standards with which the study complied, based on a Yes (Y)-No (N) binary decision.

Results

The PubMed and Cumulative Index to Nursing and Allied Health Literature searches identified 22 citations and abstracts using the combined keywords of "thoracic spine," "thoracic vertebrae," "biomechanics," "coupling," "three-dimensional," and "movement" (Table 1). A hand-search identified 34 additional citations and abstracts that were obtained for initial review, creating a total of 56 studies. Of the 56 studies identified in the searches, the first two investigators (P. S. and C. C.) reached consensus on 41 studies and required further assistance by the third independent investigator on 15 studies. Of the 41 studies reaching consensus, the two investigators agreed that 10 studies were acceptable for inclusion (ie, for further review) in the study. Conversely, 31 studies were deemed unacceptable for further review. Initial citation and abstract review produced a fair intertester reliability for study inclusion between the two investigators (K = 0.38).[17] The third investigator was employed to evaluate 15 studies, of which 11 were deemed acceptable and 4 were deemed unacceptable for further evaluation. Table 2 reflects the reasons for abstract rejection.

The 21 articles that were deemed acceptable by the distillation process were obtained for review. Of the 21 articles, 12 did not define a directional coupling pattern and did not qualify. One study met the coupling criteria but was conducted on canine cadaveric specimens and was therefore disqualified. Upon completion of the review, 8 articles were identified as plausible investigatory analyses of coupling motion of the thoracic spine (Table 3).[1,18-24] Six of the articles used thoracic motion initiation (either rotation or side-bend),[1,18-20,23,24] whereas two used upper extremity elevation to initiate the coupling behaviors.[21,22]

Two of evaluated studies reported the use of in vitro specimens for analysis (Table 3).[18,19] Panjabi et al[18] evaluated 5 fresh frozen cadaveric specimens where the majority of segmental support structures remained intact, including the ribs, costovertebral joints, and costotransversal joints. These investigators examined coupling motion in segments T1-T2 through T11-T12 during movements while loads were exerted on rigid arms attached to the cranial-most vertebra. Similarly, Oxland et al[19] evaluated 5 fresh frozen cadaveric specimens in a similar age range. However, unlike Panjabi et al,[18] all nonligamentous tissues were dissected, along with all costal structures. Moreover, this study documented the coupling behaviors only at T11-T12 and T12-L1 through a stereophotogrammetric motion recording.

Four studies examined in vivo human coupling behaviors (Table 3).[1,20-22] Willems et al[1] evaluated 30 male and 30 female young adult in vivo human subjects, measuring coupling behaviors during active spine movements using a 3-Space Fastrak system. Gregersen and Lucas[20] evaluated coupling behaviors by observing the rotational displacement of Steinmann pins that had been embedded into the subjects' spinous processes at T1 through L1. Stewart et al[21] and Theodoridis and Ruston[22] used electromagnetic tracking systems to examine thoracic coupling that was initiated through upper extremity elevation in 20 and 25 female subjects, respectively. Finally, Schultz et al[23] and Scholten and Veldhuizen[24] reported coupling behaviors established through mathematical modeling. In both studies, the disk, ligament, and bony processes were represented in the model, omitting rib mechanism representation from the mathematical analysis.

Composite Quality Scores were established for each study to analyze the quality of each study (Table 4). All 8 studies reflected intact articular tissue (standard 3), adequate description of the investigation setup (standard 6), identification of a 3-D measure (standard 7), description of movement initiation (standard 9), directional coupling patterns (standard 10), and limits to the study (standard 16). Only two studies (Stewart et al[21] and Theodoris and Ruston[22]) reported measures of reliability (standard 12). Theodoris and Ruston[22] showed the highest Composite Quality Score (100%), complying with all of the 16 quality standards. Stewart et al[21] complied with 15 of the standards (93.8%), where they only failed to evaluate single segmental levels (standard 8). Studies of Shultz et al[23] and Scholten and Veldhuizen[24] each complied with only 7 of the 16 standards, producing the lowest Composite Quality Scores.

Six studies qualified as 3-D analyses of coupling motion with rotation initiation (Table 5). Coupling behaviors in response to rotation initiation varied both between and within the previously described studies. Panjabi et al[18] reported that all segments side-bend (lateral flexion)-coupled in the same direction as the rotation when the segments were passively rotated to the left, whereas the same segments side-bend-coupled left when the segments were passively rotated right. Conversely, Oxland et al[19] reported side-bend coupling to the same direction as rotation when performed to the left or right rotation at the two most caudal thoracic motion segments. Similarly, Schultz et al[23] concluded from mathematical analysis that a side-bend coupling occurs in the same direction as the rotation.

Table 5. *Coupled thoracic motion with rotation initiation*

Author	Spine position (F, N, or E)	Direction	C7T1	T1T2	T2T3	T3T4	T4T5	T5T6	T6T7	T7T8	T8T9	T9T10	T10T11	T11T12	T12L1
Panjabi et al, 1976[18]	Neutral	(L) rotation	NT	S	S	S	S	S	S	S	S	S	S	S	NT
		(R) rotation	NT	O	O	O	O	O	O	O	O	O	O	O	NT
Oxland et al, 1992[19]	Neutral	Both (L) and (R) rotation	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	S	S
Willems et al, 1996[1]	Neutral	Both (L) and (R) rotation	NT	V			V				V				
Gregersen and Lucas, 1967[20]	Neutral	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
Schultz et al, 1973[23]	Neutral	NR	NT	S	S	S	S	S	S	S	S	S	S	S	S
Scholten and Veldhuizen, 1985[24]	Not applicable	NR	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT

S, axial rotation coupling to the same side as side-bend; O, axial rotation coupling to the opposite side of side-bend; NT, not tested;. V, variable coupling pattern among specimens; NR, not reported; F, flexed; E, extended; N, neutral; (L), left; (R), right.

Table 6. *Coupled thoracic motion with side-bend (lateral flexion) initiation*

Author	Spine position (F, N, or E)	Direction	C7T1	T1T2	T2T3	T3T4	T4T5	T5T6	T6T7	T7T8	T8T9	T9T10	T10T11	T11T12	T12L1
Panjabi et al, 1976[18]	Neutral	Both (L) and (R) side-bend	NT	O	O	O	O	O	O	O	O	O	O	O	NT
Oxland et al, 1992[19]	Neutral	Both (L) and (R) side-bend	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NC (1)	NC (1)
Willems et al, 1996[1]	Neutral	Both (L) and (R) side-bend	NT		V				V				V		NT
Gregersen and Lucas, 1967[20]	Neutral	Both (L) and (R) side-bend	S	S	S	S	S	S	S	S	S	S	S	S	O
Schultz et al, 1973[23]	Neutral	NR	NT	S	S	S	S	S	S	S	S	S	S	S	S
Scholten and Veldhuizen, 1985[24]	Flexion and extension	NR	NT	S	S	S	S	S	S	S	S	S	S	S	S

NC indicates no coupling observed.

However, they did not identify the specific rotation direction. Finally, Willems et al[1] reported differences in coupling directions depending on the regions of the thoracic spine. When rotation was the primary motion, it was accompanied by ipsilateral side-bend coupling in (1) 18% of subjects at segments T1T2 through T3T4; (2) 99% of subjects at segments T4T5 through T7T8; and (3) 93% of subjects at segments T8T9 through T11T12. The remainder of subjects produced contralateral side-bend coupling within each segmental region.

Six studies qualified as 3-D analyses of coupling motion with side-bend initiation (Table 6). In a similar fashion to the rotation-initiated coupled movements, side-bend–initiated movements produced varying results depending on the investigator. Panjabi et al[18] reported that all segments showed rotation coupling in the opposite direction as the side-bending to either left or right (T1T2 through T11T12), whereas Oxland et al[19] reported no rotation coupling when the T11T12 or T12L1 segments were passively side-bent. Willems et al[1] reported regional differences in rotation coupling in a similar fashion to the previously reported side-bend coupling. When side-bending was the primary motion, it was accompanied by axial rotation in approximately 2:1 (T1-T4), 1:1 (T4-T8), and 3:1 (T8-T12) ratios. The side-

Table 7. *Coupled thoracic motion with upper extremity initiation, side-bend, or rotation initiation was not reported*

Author	Spine Position (F, N, or E)	Direction	C7T1	T1T2	T2T3	T3T4	T4T5	T5T6	T6T7	T7T8	T8T9	T9T10	T10T11	T11T12	T12L1
Stewart et al, 1995[21]	NR	(R) UE elevated	NT			V (1)						V (2)			NT
Theodoridis and Ruston, 2002[22]	NR	Both (L) and (R) UE elevated	NT	NT	V	V	V	V	V	NT	NT	NT	NT	NT	NT

Spine position was not reported.
UE indicates upper extremity.

bend movement was accompanied by ipsilateral rotation coupling in (1) 47% of subjects at segments T1-T2 through T3-T4; (2) 83% of subjects at segments T4-T5 through T7-T8; and (3) 68% of subjects at segments T8-T9 through T11-T12. The remainder of subjects produced contralateral rotation coupling within each segmental region.

Two studies reported coupled thoracic motion in response to active upper extremity elevation initiation (Table 7). In both studies, side-bend or rotation initiation was not reported, as well as a lack of spine position. Theodoridis and Ruston[22] evaluated the coupled thoracic movements in the T2-T3 through T6-T7 segments during left and right upper extremity elevation in both the sagittal and scapular planes. They reported that 92% of the subjects produced ipsilateral thoracic rotation and side-bending-coupled movement during flexion of both the right and left upper extremities, whereas 8% produced contralateral coupling. Conversely, elevation in the scapular plane produced ipsilateral coupling in 76% of the subjects, whereas 24% exhibited contralateral coupling.

Stewart et al[21] examined the coupling behaviors produced during active right upper extremity elevation. For segments T1-T2 through T5-T6, 8 subjects produced ipsilateral thoracic spine coupling, whereas 12 produced contralateral coupling. Of those subjects producing ipsilateral coupling, 6 subjects coupled to the right, whereas 2 coupled to the left. Of those coupling contralaterally, 7 coupled with right rotation and left side-bending, whereas 5 coupled with left rotation and right side-bending. In segments T6-T7 through T11-T12, 14 subjects produced ipsilateral coupling, whereas 6 produced contralateral coupling. Of those subjects that produced ipsilateral coupling, 4 subjects coupled to the right, whereas 10 coupled to the left. Of those that produced contralateral coupling, 5 subjects coupled with right rotation and left side-bending, whereas 1 coupled left rotation and right side-bending.

Discussion

There are two notable findings in this review. First, there is poor agreement among 3-D biomechanical studies that identified coupling behavior of the thoracic spine. Variations were reported in side-bending and rotation initiation, and no consistent pattern was observed when comparing in vivo vs in vitro findings. Coupling motion secondary to upper extremity movement resulted in the greatest display of variation. Taken at face value, the findings suggest that thoracic spine coupling patterns are inconsistent. Second, there was significant variation observed regarding study designs, measurement methods, and tissue preparation for each study. Variations in methodology may account for differences among the findings in each study.[25,26] For example, tissue preparation ranged from removal of all ribs and corresponding ligaments to maintenance of all anatomical structures. This may have contributed to differences in coupling outcomes.

Abnormalities associated with quality and direction of coupling could be construed as pathological and have been associated with physical variation or dysfunction.[12,14] Because many manual therapy clinicians base specific mobilization and manipulation decisions on selected theories of coupling, such as Fryette laws,[27,28] variations in treatment application are possible as result of inconsistencies between theories.[28] The feasibility exists, that if practicing therapists do not share consistent directional coupling pattern expectations, the results of their assessment and treatments may be dissimilar.

It has been recognized that 2-D analysis of coupling spinal motions are inaccurate at measuring axial rotation and may be ineffective at measuring coupling direction and quantity.[25] Two-dimensional imagery has been criticized because of the potential magnification of errors, projection of translations as rotations, and misleading results.[26,29] To represent the true accurate motion behavior of the spine, intervertebral coupling motion is best measured with 3-D instrumentation,[25,30] which allows the calculation of finite movements in multiple planes. Thus, we elected to include only studies that used 3-D imagery.

This review found that under controlled in vitro conditions, variations of the coupling pattern of the thoracic spine are present, which indicates variability of thoracic coupling in controlled conditions both with side-bend initiation and rotation initiation. Although 3-D analyses have shown the greatest degree of accuracy, translating the results of in vitro studies into the clinical setting is questionable. In vitro studies involve cadaveric specimens with selected tissue removed, such as muscles, ligaments, and/or rib structures. In addition, different investigators test different combinations of thoracic segments using different variations of applied load.[18,31] These changes produce alterations in tissue flexibility and resultant coupling behavior of the spine.[18] Nonetheless, in vitro studies can be useful because they allow for the control of extraneous variables, such as the load that is applied; the passivity of motion (no muscle activity); prepositioning of the spine in a flexed, neutral, or extended position; and the degree of kyphosis and/or scoliosis,[32] which all can influence the coupling behavior of the thoracic spine.[24]

In vivo studies are clinically applicable but lead to challenges in controlling extraneous variables that include motor and postural control, as well as tissue adaptation[33] anatomical and circadian variability; applied preload forces [12,18,34,35]; the degree of thoracic kyphosis and scoliosis [36]; and technical difficulty in measuring spinal coupling.[20] For example, most of the studies reported in this systematic review, with the exception of one study, measured the coupling of the thoracic spine in its neutral position. This could create variability in measurement outcomes due to the considerable variance in the position that the investigators considers 'neutral,' which appears to depend on the degree of thoracic kyphosis. The finding of Scholten and Veldhuizen[24] that coupling is stronger in a flexed position of the thoracic spine supports this notion, which may partially explain selected disparities in the findings of this review. Further supporting this idea, Stewart et al[21] used women aged 18 to 22 years with no excessive kyphosis and found no significant pattern of thoracic coupling in a neutral position using arm elevation, whereas Theodoridis and Ruston[22] used an older sample of women aged 45 to 64 and found predominance of ipsilateral thoracic coupling. In addition, similar findings were identified in a study involving manual palpation of thoracic segmental motion that reported 90% of young men exhibiting an ipsilateral 3-D movement in thoracic spinal extension, whereas a contralateral 3-D movement was reported in 91% of young women in a position of thoracic extension.[37] These results may reflect the interaction of the thoracic kyphosis with sex-related differences in spinal stiffness and segmental behaviors that have been previously described.[38,39]

This is the first manuscript we are aware of to score the quality of manuscripts addressing coupling behaviors of the spine. The results of this scoring provide details regarding the differences observed between the study outcomes. A lack of any reliability measure in most of the evaluated studies suggests a considerable limitation in the available data to date and implies the need for this consideration in future studies. The compliance of all 8 studies with several of the standards creates a foundation for assessing the quality of biomechanical studies at other spinal regions. Moreover, the standards may suggest a basis for future study design when addressing biomechanical behaviors of the spine.

It has been stated that knowledge of spine mobility and characteristics of coupling direction are important for understanding and treating patients with spinal pain.[18] At present, the evidence to support this view is wanting. The 3-D thoracic movement research using in vivo human subjects tested the coupling of the thoracic spine in neutral position with the exception of one investigation.[24] Both side-bend– and rotation-initiated results are inconsistent. Most manual, segmental therapeutic techniques that are based on coupling theory use side-bend initiation. With the findings of this review in mind, this approach should be questioned, unless preceded by a reliable and valid segmental movement testing procedure.

All 3-D in vivo studies published to date included asymptomatic subjects only. The findings have limited application to a symptomatic patient population with thoracic pain. Thus, the need for additional research investigating the coupling pattern of the thoracic spine in symptomatic subjects is merited, considering that patients with spinal pain display greater levels of guarding, recruit muscle activity differently, move slower, and have altered range of motions compared with asymptomatic individuals.[40]

The lack of a common coupling pattern may merit individual clinical assessment for each patient examined. However, the reliability and validity of such clinical measurement must serve as a prerequisite for the use of manual testing in the clinic. Brismee et al[37] examined the intertester reliability of a passive physiological intervertebral motion test of the mid thoracic spine in live asymptomatic subjects. This measure used thoracic motions in 3 dimensions, whereas investigators tested the relative movements of the spinous processes. These investigators observed fair to substantial reliability between 3 experienced manual therapy examiners in evaluating mid thoracic segmental mobility. Although this study could represent a foundation for developing a method for clinical testing, further investigations are merited to establish the validity of testing that measures thoracic segmental coupling movements in symptomatic subjects. In the absence of any available valid test for clinical determination, clinicians must then reconsider the limited value of coupling information for the diagnosis and treatment of thoracic spine conditions.

Conclusion

Findings suggest that the coupling of the thoracic spine is inconsistent and, if used in clinical reasoning and methodology, may merit specific segmental testing. More rigorous, in vivo investigations are needed to evaluate the coupling pattern of the thoracic spine in symptomatic subjects prepositioned in both thoracic flexion and extension. Present studies on coupling behavior may yield some useful information, but clinicians need to recognize that not all individuals will display the same mechanical behaviors.

Practical Applications

- Of 56 identified studies, 8 met the inclusion criteria and showed variations in coupling behaviors findings.
- Differences in study design, measurement method, and tissue preparation may have contributed to differences between studies.

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