Thoracic Coupled Motions of Korean Men in Good Health in Their 20s

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Abstract. [Purpose] The purpose of this study was to investigate thoracic coupled motions of 20 Korean young
individuals. [Methods] Thoracic motion of twenty healthy male college students aged 23.2±3.1 was examined. The
coupled motions of the thoracic regions T1–4, T4–8, T8–12 were measured using a three dimensional motion cap-
ture system. [Results] Coupled axial rotation in the same direction as lateral bending was observed in T1–T4 and
T4–T8 in the neutral, flexed, and extended postures of the thoracic spine. In T8–T12, coupled axial rotation in the
same direction as lateral bending were observed in the neutral and flexed postures, while coupled axial rotation in
the opposite direction was observed in an extended posture. [Conclusion] The patterns of coupled motions in the
thoracic spine demonstrated some variability between postures and regions *in vivo*. However, coupled motions in
the same direction were predominantly lateral flexion or axial rotation in the three postures.
Key words: Coupled motion, Three-dimensional motion capture system, Thoracic spine

INTRODUCTION

Lateral bending of the thoracic spine does not involve pure lateral bending but accompanies rotation[1]). Motions accompanying unintended movements or motions in unintended directions, are named coupled motions[1, 2]), and when they have certain patterns, these are called coupled motion patterns. Manual therapists evaluate and treat their patients' thoracic pathologies based on their coupled motions[1, 3, 4]); therefore, accurate knowledge of their patients' coupled motions is very important. However, researchers have often presented conflicting research outcomes on the directions of coupled motions, which are the theoretical background for manual treatment of the thoracic spine.

According to the theory of coupled motion proposed by different clinicians, the thoracic spine and the lumbar spine have certain patterns according to position. Panjabi et al.[3])

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noted that during lateral bending of the thoracic spine in the neutral position, the coupled axial rotation occurrs in the opposite direction (e.g. left lateral bending with right rotation). Kaltenborn[5]) and Stoddard[4]) observed that in a extended position, coupled motion occurs in the opposite direction during lateral bending, while in a flexed position, coupled rotation occurrs in the same direction during lateral bending. In the area of osteopathy, when rotation occurs in the opposite direction during lateral flexion, it is named Type 1, and when rotation occurs in the same direction during lateral flexion, it is named Type 2. Gibbons et al.[1]) and Kaltenborn[5]) applied joint mobilization and manipulation based on the coupled motion theory. However, if the coupled motion theory is not accurate, evaluation and treatment based on it would not be accurate either, and treatment effects would not be guaranteed.

In recent research, Oxland et al.[3]) observed that coupled axial rotation did not occur at all in the T11–T12 and T12–L1 during lateral bending. Willems and Jull[6]) reported variations in accordance with the regions of the thoracic spine in subjects in a neutral position. Also, during lateral bending, the rates of coupled axial rotation in the same direction were 47% in the T1–T4, and 83% in the T4–T8, and 68% in the T8–T12. Their conclusion was that lateral bending of the

thoracic spine in the same direction was more prominent than in the opposite direction in a flexed position, while lateral bending of the thoracic spine in the opposite direction was more prominent, both in the neutral and extended positions[7].

In previous research, coupled motions of the thoracic spine have been measured by 2-dimensional (2D) radiation imaging, often using cadavers[3, 8, 9]. 2D techniques have been criticized for incorrect readings, magnification errors, or misinterpretation of projected bone movements as rotations. It has been reported that experiments on cadavers with their muscles removed have merits, in that researchers can precisely measure thoracic coupled motions, but they cannot accurately reflect muscular activities of each position, or the exact load effects. From the above, we can infer that the reports of lateral bending of the thoracic spine have been inconsistent among researchers, and have been subject to a lot of controversies, due to lack of validation[7].

Panjabi et al.[8] noted, movement of the spine is made in three dimensions and in order to measure coupled motions of the spine intervertebral motions should be measured in three dimension to effectively show actual spinal movements. This study was conducted in order to provide biomechanical data on coupled motions (T_{1-4}, T_{4-8}, T_{8-12}) using 3-dimensional (3D) motion capture analysis during lateral bending of the thoracic spine by 20 healthy Korean male college students, in the neutral, flexed and extended postures.

Most theories of coupled motion are based on Western studies. While some recent studies have reported that coupled motions do not exhibit a specific pattern, there are few studies of the coupled motions of Koreans. Therefore, the purpose of this study was to provide the biomechanical information necessary for performing orthopedic manipulative therapy for Koreans, by examining the coupled motions of the backbones of Korean college student in their 20s.

SUBJECTS AND METHODS

The study subjects were recruited open application from students at K University located in Geonbuk Province. Thirty subjects applied, and those who had a history of pain or damage to the thoracic vertebrae area within the previous one year, who had restrictions in their daily life due to spinal problems, had a respiratory problem for a long time, or had received a surgery of the spinal area were excluded, 20 subjects (men) were finally selected. This study was approved by University's Research and Ethics Committee. The purpose and content of this study was explained to the subjects and their consent to participation in this experiment was obtained.

3D research on coupled motions is accepted as being more accurate than 2D research at capturing thoracic spinal movement patterns[3]. This study used a 3D motion capture system (LUKOtronic, Lutz-Kovacs-Electronics, Austria) in order to analyze coupled motions of the thoracic spine. This system consists of three infrared cameras and dynamic infrared reflective skin markers. At a distance of 2.8 meters from the rear of the subject, the 3D motion analysis system was installed in order to photograph thoracic coupled motions. The system's optical axis was installed at a height of around 1.1 meters and maintained as horizontal as possible, parallel to the ground.

A computer (Averatec 7100, TriGem Computer, Korea) and a motion analysis program (AS202, Lutz-Kovacs-Electronics, Austria) were used to analyze coupled motions during lateral bending of the thoracic spine. The width, length, and height of the chair, specially designed for this study, were, respectively, 50 cm, 77 cm, and 46 cm, and the height of the lumbar support was 24 cm. The chair was designed to move forward and backward to adjust to each subject's femoral length.

For the reflective marker attachment, the subjects took off their upper garment. They initially had their skin surface sterilized with alcohol, so that the reflective markers could be attached well. First, two reflective markers were attached to the upper back of the lumbar support (each marker evenly spaced at 2 cm to the right and left of the support's vertical midline) to provide a reference value for coupled motions occurring during lateral bending. To minimize the displacement of the subject's reflective markers, that might have resulted from skin movement, three markers per vertebrae, were attached to the spinous processes and to the right and left transverse processes of T1, T4, T8, and T12 while subjects were in a 30° flexed position. The spinous process of T1 was found at one level below C7; that of T4 was detected by palpating three spinous processes below T1; that of T8 was detected by palpating four spinous processes below T4. The fourth point, T12, was found by palpating four spinous processes below T8 and its location was confirmed by counting upward from the central point (the second sacrum) of the line connecting the posterior superior iliac spine. The T1 transverse process were detected by palpating the points 1.5 cm lateral to either side of the C7 spinous process, the T4 transverse processes at 2 cm symmetrically lateral to the T3 spinous process, the T8 transverse processes at 2 cm symmetrically lateral to and also vertically between the T6 and T7 spinous processes, and the T12 spinous processes at 2 cm symmetrically lateral to the T11 spinous process. A skillful physical therapist who had completed orthopedic manual therapy of Kaltenborn-Evjenth concept, and spinal management courses, performed the palpation and attached all of the reflective markers. Intra-tester reliability was 0.94. Therefore, the reflective markers attached to the transverse processes well reflected lateral flexion and coupled rotation of the thoracic vertebrae during the dynamic movements this study examined.

A 3D motion analysis system was used to analyze the coupled motions of the thoracic spine. Regarding the three-dimensional coordinate system, the Y-axis was defined as vertical to the horizontal plane, the X-axis as the anteroposterior direction, and the Z-axis as the mediolateral direction. Data were collected at a sampling rate of 60 Hz.

The lateral flexion angle of T1–T4 was calculated as the angle between the line which horizontally connected the reflective marker attached to the lumbar supporter from the coronal plane (Y, Z) and the line which connected the T1-T4 spinous process (SP). The lateral flexion angle of T4–T8
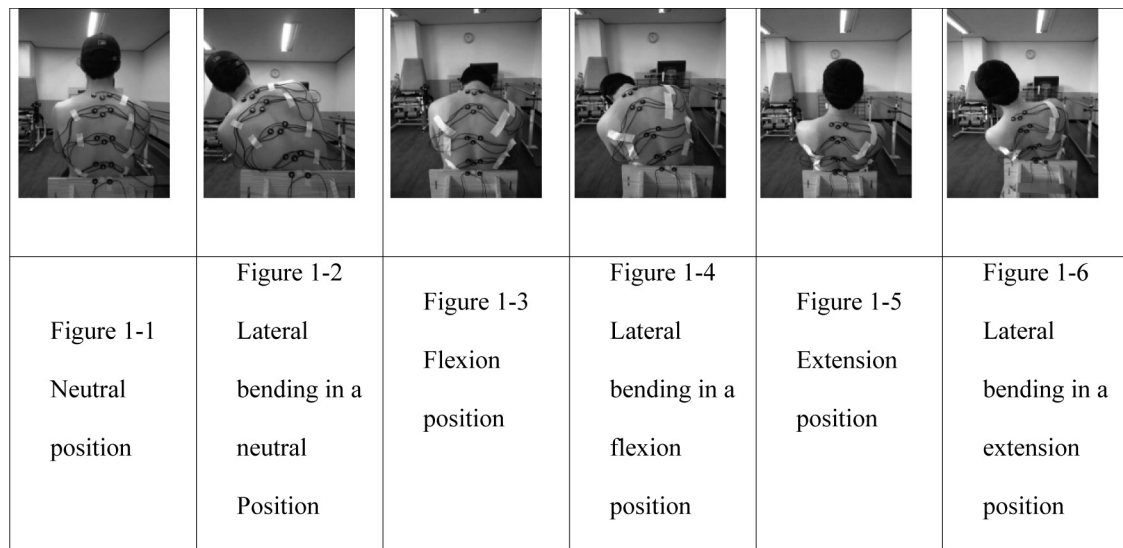
| | Figure 1-2 Lateral bending in a neutral Position | Figure 1-3 Flexion position | Figure 1-4 Lateral bending in a flexion position | Figure 1-5 Extension position | Figure 1-6 Lateral bending in a extension position |
| Figure 1-1 Neutral position | | | | | |

Fig. 1. Subject's position

was calculated as the angle between the line that horizontally connected the reflective marker attached to the lumbar supporter and the line that connected the T4–T8 SP. The lateral flexion angle of T8–T12 was calculated as the angle between the line that horizontally connected the reflective marker attached to the lumbar supporter and the line that connected the T8–T12 SP. As for the coupled rotation angles of T1–T4, T4–T8, and T8–T12, the rotation angle of the line that connected the bilateral transverse processes of T1, T4, T8, and T12 with the vertical axis as the center was derived. Then the angle between the lines that horizontally connected the reflective marker attached to the lumbar supporter was calculated. The T1–T4 coupled rotation angle was obtained by subtracting the T4 rotation angle from the T1 rotation angle; the T4–T8 coupled angle was obtained by subtracting the T8 rotation angle from the T4 rotation angle; and the T8–T12 coupled angle was obtained by subtracting the T12 rotation angle from the T8 rotation angle. When the rotation angle was positive, it was defined as ipsilateral rotation, and when the rotation angle was negative, it was defined as contralateral rotation.

For analysis of coupled motions of the thoracic spine, we referred to the experimental method of Willems and Jull. A neutral posture was defined as a comfortable straight sitting position with the pelvis and waist fixed on the support, a flexed posture as a position with the thoracic spine flexed to the maximum level (pelvis and waist fixed), and an extended posture as a position with the thoracic spine extended to the maximum level (pelvis and waist fixed). Sitting straight on the wooden chair with the lumbar support, the subject had the knee joints flexed at 90°, with both feet placed close together and maintained flat on the floor.

The right arm was comfortably placed on the left shoulder and the left arm on the right shoulder. In order to observe motions that occur purely due to the thoracic spine, excluding lumbar spinal and pelvic movements during flexion and extension, each of the regions was fixed to the chair using the lumbar support, a pelvic belt, and a femoral belt. A loca-

tion board was placed at a distance of 60 cm in front of the subject, so that the subject's trunk could be returned to the same location when returning to the starting position after lateral bending. The subject returned to the starting position each time, after lateral bending was performed to the maximum level in the neutral, flexed and extended postures (Fig. 1). Each lateral bending period was 1 minute so as to minimize subjects' trunk muscle fatigue. Each motion was performed three times and the mean value was calculated.

The means and standard deviations of all measured variables were calculated using SPSS 15.0. A one-way ANOVA was performed to examine differences between each of the three positions and the Bonferroni correction was conducted as a post-hoc test. A p-value of ≤0.05 was considered statistically significant.

RESULTS

Lateral bending angles of the thoracic spine (T1–T4) were larger in the neutral posture than in the flexed and extended postures of the thoracic spine, but they were not significantly different statistically (neutral: 30.7±5.9, flexed: 28.8±11.7, and extended: 28.4±4.8). Also, lateral bending angles of the thoracic spine (T4–T8) were larger in the neutral posture than in the flexed and extended postures, but they were not significantly different (neutral: 24.6±5.4, flexed: 20.7±10.9, and extended: 22.1±5.0). Likewise, lateral bending angles of the thoracic spine (T8–T12) were larger in the neutral posture than in flexed and extended postures, but they were not significantly different (neutral: 17.4±6.4, flexed: 12.9±6.5, and extended: 13.8±6.2) (Table 1).

Lateral bending of the thoracic spine (T1–T4) was accompanied by coupled axial rotation in the same direction in the neutral, flexed, and extended postures. Coupled axial rotation was larger in the neutral and extended postures than in the flexed posture, but the differences were not statistically significant (neutral: 1.6±1.5, flexion: 2.8±2.3, and extension: 1.9±1.1). The directions of coupled axial rota-

Table 1. Subjects' lateral bending and coupled rotation (n=20)

Posture	T1–4		T4–8		T8–12	
	LB	CR	LB	CR	LB	CR
Neutral	30.7 (5.9)	1.6 (1.5)	24.6 (5.4)	3.0 (2.4)	17.4 (6.4)	2.7 (2.8)[‡]
Flexion	28.8 (11.7)	2.8 (2.3)	20.7 (10.9)	2.0 (2.4)	12.9 (6.5)	4.4 (2.4)[δ]
Extension	28.4 (4.8)	1.9 (1.1)	22.1 (5.0)	0.7 (2.8)	13.8 (6.2)	−1.0 (2.0)

LB: lateral bending; CR: coupled rotation; Value are mean (SD)
[‡]: significant difference between Neutral and Extension position, p<0.05
[δ]: significant difference between Flexion and Extension position, p<0.05
+: indicates the same direction as lateral bending for coupled rotation and flexion
−: indicates the opposite direction to lateral bending for coupled rotation and extension

tion of the thoracic spine (T4–T8) were similar to those of the thoracic spine (T1–T4); Lateral bending of the thoracic spine (T4–T8) accompanied coupled axial rotation in the same direction in the neutral, flexed, and extended postures. Coupled axial rotation was larger in the neutral posture than in the flexed and extended postures, but the differences were not statistically significant (neutral: 3.0±2.0, flexion: 2.0±2.4, and extension: 0.7±2.8). Meanwhile, lateral bending of the thoracic spine (T8–T12) accompanied coupled axial rotation in the same direction as that of the neutral and flexed postures and in the opposite direction in the extended posture. Coupled axial rotation was larger in the neutral and flexed postures than in the extended posture, but the differences were not statistically significant (neutral: 2.7±2.8, flexed: 4.4±2.4, and extended: −1.0±2.0) (p<0.05) (Table 1).

DISCUSSION

All primary motions accompany other planar movements[2, 4]. In particular, lateral bending and axial rotation accompany each other and such motions are called coupled motions[2]. According to a study of cadavers, coupled motions are most prominent between lateral bending and rotation, and between rotation and lateral bending[5]. For easy understanding of coupled motions, flexion-extension, axial rotation, and lateral bending motions should be explained through simple angles or numbers, or illustrated by a three-dimensional animation using a 3D motion capture system[10]. This study was able to measure the angles and directions of coupled motions during lateral bending using a 3D motion capture system. In the thoracic vertebrae, rotation was more predominant than lateral flexion. However, in the orthopedic manual therapy, when mobility of the thoracic vertebrae is evaluated or its treatment is made, the subject is laid in a side lying position and lateral flexion is made to the right and left directions to examine the coupled motion. Therefore, this study also conducted lateral flexion first and observed the coupled motion accompanying it.

Panjabi et al.[9] noted that in the neutral posture lateral bending of the thoracic spine (T1–T4), (T4–T8), and (T8–T12) accompanied coupled axial rotation in the same direction, in the opposite direction, and in the same or opposite direction, respectively. Scholten and Veldhuizen[11] noted that the displacement of each thoracic region was due to the vertebral bodies being in the sagittal plane. Also, if the thoracic region had an anterior tilt, coupled axial rotation oc-

curred in the same direction, but if they had a posterior tilt, coupled axial rotation occurred in the opposite direction, suggesting that controversies in the literature arise from diverse definition of the sagittal plane. Kaltenborn[6] noted that in C2–T3 of the cervical and thoracic spines coupled axial rotation was in the same direction regardless of whether the subject was in a flexed or extended posture, while in the T4–L5, the directions of coupled axial rotation differed according to postures, with coupled axial rotation occurring in the same direction in a flexed posture and in the opposite direction in an extended posture. Greenman[12] observed that coupled rotation occurred in the opposite direction during lateral flexion in the thoracic vertebrae with kyphosis in the middle area, and when rotation was made first, lateral flexion occurred in the same direction. However, Willems and Jull[6] reported that 47% of the motion in T1–T4, 83% in T4–T8, and 68% in T8–T12 involved coupled axial rotation occurring in the same direction as lateral bending, showing that coupled axial rotation in the same direction as lateral bending occurred most prominently in the T4–T8 in neutral position. In the present study, especially, in the T1–T4 and T4–T8, lateral bending accompanied coupled axial rotation in the same direction regardless of position (neutral, flexed, and extended positions) the while in T8–T12, lateral bending accompanied coupled axial rotation in the same direction with the subject in the neutral and flexed postures, and in the opposite direction with the subject in an extended posture. Overall, coupled axial rotation occurring in the same direction was more prominent than that in the opposite direction. The results of this study are consistent with those of Willems and Jull[6], in that coupled axial rotation in the same direction was more prominent than that in the opposite direction in T4–T8 and T8–T12 during lateral bending, and the rates of coupled axial rotation that occurred in T1–T4 in the same direction and in the opposite direction were similar. Coupled motions during lateral bending of the thoracic spine may be explained by the structural form and movement of the posterior articular surface[8]. During lateral bending, one side of the articular surface moves upward and forward, while the other side moves downward and backward. Lateral bending, a combination of upward movement in one direction and downward movement on the other side of the spine, automatically creates forward movement in one direction and backward movement in the other direction, resulting in coupled axial rotation occurring in the same direction. Therefore, left axial rotation is

coupled with left lateral bending. Penning and Wilmink[9] proposed that the rib head plays the same role as that of the uncinate processes of the cervical spine, which regulate coupled axial rotation occurring in the same direction during lateral bending. In the present study, coupled axial rotation occurred in the same direction more often than in the opposite direction during lateral bending as by Penning and Wilmink[9]. In the present study, the results differed from a former study on coupled motions of cadavers[3]. This is because the present study attached reflective marks to the subjects' skin and measured coupled motions during active lateral flexion. However, the cadaver study performed tests during passive lateral flexion created by the researcher. In particular, in the present study, the involvement of the subject' trunk muscles in the processes of lateral flexion may have had, at least, a minor level of impact on the coupled motions of the subjects. The present experiment did not investigate how muscular activities of the body influenced coupled motions. Nonetheless, it is meaningful in that research on active coupled motions was performed with the subjects' costal bones, muscles, and other soft tissues intact and under apparently normal neurological conditions.

According to our present results, coupled motion did not always have a certain pattern, and lateral flexion and coupled motion were ipsilaterally predominant. It can be inferred that the subjects' subtle anatomical differences and soft tissue tension and asymmetry of motor control exerted effects.

This study is meaningful in that it employed a 3-dimensional motion analysis system to observe coupled motion of the thoracic vertebrae. However, whether anatomical structure and motor control affected coupled motion was not investigated. Therefore, relevant additional research is considered necessary. In addition, the subjects were limited to healthy male college students in their 20s, and therefore additional research with females, subjects of different ages, and those with pathological problems is necessary. Finally, each subject has a different direction of coupled motion and clinicians need to be cautious when applying orthopedic manual therapy based on coupled patterns, and we consider a new approach of customized orthopedic manual therapy suitable for subjects is necessary.

REFERENCES

1) Gibbons R, Tehan R: Muscle energy concepts and coupled motion of the spine. Man Ther, 1998, 3: 95–101. [CrossRef]
2) Bogduk N: Clinical Anatomy of the Lumbar Spine and Sacrum. Churchill Livingstone, 1997.
3) Oxland TR, Lin R, Panjabi M: Three-dimensional mechanical properties of the thoracolumbar junction. J Orthop Res, 1992, 10: 573–580. [Medline] [CrossRef]
4) Stoddard A: Manual of Osteopathic Technique, 5th ed. An chor Press Ltd, 1980.
5) Kaltenborn F: The Spin, 2nd ed. Olaf Norlis Bokhandel, 1993.
6) Willems JM, Jull G: An in vivo study of the primary and coupled rotations of the thoracic spine. Clin Biomech (Bristol, Avon), 1996, 11: 311–316. [Medline] [CrossRef]
7) Sizer PS, Brisme'e M, Cook C: Coupling behavior of the thoracic spine: a systematic review of the literature. J Manipulative Physiol Ther, 2007, 30: 390–399. [Medline] [CrossRef]
8) Panjabi MM, Brand R, White A: Mechanical properties of the human thoracic spine as shown by three dimensional load-displacement curves. J Bone Joint Surg Am, 1976, 58: 642–652. [Medline]
9) Panjabi M, Chang D, Dvorak J: An analysis of errors in kinematic parameters associated with in vivo functional radiographs. Spine, 1992, 17: 200–205. [Medline] [CrossRef]
10) Ishii T, Mukai Y, Hosono N: Kinematics of the cervical spine in lateral bending in vivo three dimensional analysis. Spine, 2006, 31: 155–160. [Medline] [CrossRef]
11) Scholten PJ, Veldhuizen A: The influence of spine geometry on the coupling between lateral bending and axial rotation. Eng Med, 1985, 14: 167–171. [Medline] [CrossRef]
12) Greenman: Principles of Manual Medicine. Philadelphia: Williams & Wikins, 1996.