

In Vivo 3D Intervertebral Motion Analysis of the Cervical Spine in Lateral Bending using 3D-MRI

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INTRODUCTION

In vivo 3D motion of the cervical spine has not been documented until now, since they are too complicated to follow with conventional radiographs or CT. Although *in vitro* studies using cadaver specimens reported data on the cervical 3D motion, it might not actually reflect physiological motion due to the lack of tonus of musculature. Moreover, understanding 3D motions with only a numerical combination of rotations and translations was difficult. To overcome these problems, we developed a quite unique *in vivo* 3D motion analysis system using 3D-MRI, which can make the 3D animation of the motion, and reported the kinematics of the cervical spine in rotation using this system [1,2]. The purpose of this study is to demonstrate for the first time *in vivo* 3D intervertebral motions of the cervical spine in lateral bending.

METHODS

Twelve healthy volunteers underwent 3D-MRI of the cervical spine in 7 positions with 10° increments during lateral bending using a 1.0-T imager. Relative motions of the cervical spine were calculated by automatically superimposing a segmented 3D-MRI of the vertebra in the neutral position over images of each position using volume registration, which is a method to determine relative position between two volume images by means of superimposing two 3D images to make each voxel value coincide each other maximally, and correlation coefficient was used as similarity measure. Three-dimensional motions of adjacent vertebrae were represented with six degrees of freedoms by Euler angles and translations on the coordinate system defined by Panjabi, and visualized in animations using surface bone models reconstructed with marching cubes algorithm in the Visualization Toolkit (VTK). As we have already declared, the accuracy of this system was 0.24° for flexion-extension, 0.31° for lateral bending, and 0.43° for axial rotation. Mean absolute translational error was 0.52 mm for superior-inferior translation, 0.51 mm for anteroposterior translation, and 0.41 mm for lateral translation. [1].

RESULTS AND DISCUSSION

Mean maximum lateral bending of the cervical spine to one side in maximum head lateral bending (30.3°) was 1.9° at Oc/C1, 1.6° at C1/2, 3.7° at C2/3, 3.5° at C3/4, 3.3° at C4/5, 4.3° at C5/6, 5.7° at C6/7, and 4.1° at C7/T1. C6/7 showed the larger lateral bending than other levels ($P < 0.05$). Coupled axial rotation in the opposite direction to that of lateral

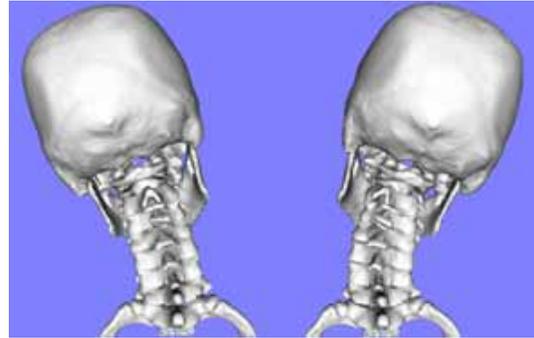


Figure 1: Cervical motion in left and right lateral bending

bending was observed in the upper cervical levels (Oc/C1, 0.2°; C1/2, 17.1°), while in the subaxial cervical levels, it was observed in the same direction as lateral bending except for C7/T1 (C2/3, -0.9°; C3/4, -1.8°, C4/5, -1.1°, C5/6, -1.2°; C6/7, -0.8°; C7/T1, 0.4°). Coupled flexion-extension was small at all vertebral levels ($< 1.1^\circ$).

In our previous study, we documented that axial rotation of subaxial cervical spine accompanied lateral bending in the same direction as axial rotation. Thus, coupling patterns of subaxial cervical spine were similar between lateral bending and axial rotation. We speculated that the upper cervical spine compensates for subaxial ipsi-axial rotation during head lateral bending by contra-axial rotation.

We could investigate *in vivo* 3D motions of the cervical spine accurately, quantitatively and non-invasively with the use of 3D-MRI to eliminate radioactive exposure. Our system facilitates not only mathematical descriptions of 3D motions, but also 3D visualization of this information, and enabled us to easily understand complicated coupled motion of the cervical spine.

CONCLUSIONS

1. We developed a novel *in vivo* 3D motion analysis system and succeeded in disclosing the *in vivo* coupled motions of the cervical spine in lateral bending for the first time.
2. Lateral bending increases as the cervical level goes downwards, and coupled axial rotation of subaxial cervical spine is in opposite direction to that of the upper cervical spine.

REFERENCES

1. Ishii T, et al. *Spine* **29**, E139-144 2004.
2. Ishii T, et al. *Spine* **29**, 2826-2831 2004.

Table 1: Mean Range (°±SD) of 3-D Intervertebral Motions on one side

Motion	Cervical			Level				
	Oc-C1	C1-C2	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-T1
Main Lateral bending	1.9(0.9)	1.6(1.3)	3.7(2.0)	3.5(1.4)	3.3(1.0)	4.3(1.4)	5.7(1.9)	4.1(2.7)
Coupled Axial Rotation	0.2(1.0)	17.1(4.7)	-0.9(0.9)	-1.8(0.7)	-1.1(0.9)	-1.2(1.0)	-0.8(0.9)	0.4(1.0)
Coupled Flexion-Extension	-1.1(1.4)	0.2(2.0)	0(0.9)	0.5(0.9)	0.8(1.0)	0.7(1.2)	0.4(1.8)	0.5(1.5)