In vitro 3D-Arthrokinematic Analysis of Axial rotation and Lateral bending mobilization of the Upper Cervical Spine

Analysis of coupled motions by cross-correlation, ratio and phase shift characteristics

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Abstract*— This paper presents an analysis of patterns of coupled motion between axial rotation and lateral bending in the upper cervical spine in an in vitro set-up. Hereby, motions were induced manually. The use of cross-correlation, ratio and phase coefficients showed to offer a more precise approach for the analysis of coupling patterns than comparing the values of the coupled motion components at the peak values of the main motion.

Keywords: atlanto-axial, manual mobilization, coupled motion, athrokinematics, cross-correlation, ratio, phase shift

I. Introduction

Three dimensional aspects of segmental motion coupling patterns in the cervical spine have been studied sparsely and mainly in laboratory situation applying pure moments of forces to induce planar motions [1, 2, 3] . Only preliminary information exists on the kinematics of manual segmental mobilization serving to manual therapy [4, 5, 6, 7]. The present study focuses on the in vitro registration of upper cervical segmental coupled motions during manually performed axial rotation and lateral bending mobilization. The aim of the study was to collect qualitative information on the kinematics behavior and motion coupling patterns between axial rotation and lateral bending at the atlanto-axial motion segment during planar induced movements applying manual therapeutic mobilization techniques. Such information can be helpful in understanding the effects of manual therapy on spinal motion.

II. METHODS

One fresh and nine embalmed cervical spine specimens from the occipital level to the first thoracic spine were taken from human cadavers. Each specimen was clamped on a rigid stand by fixing T1, leaving the cervical spine fully free to move. 3D-electromagnetic tracking sensors (Flock of Birds-Ascension Technologies) were fixed on C1 and C2. Subsequently, each specimen was first mobilized in a functional anatomical axial rotation and later in a lateral bending direction while the position and orientation of each sensor were collected. At a later stage, the positions of local anatomical landmarks were digitized using a 3D drawing stylus (3DX-Microscribe). The individual sensor data were used to describe coupled movements between atlas and axis by means of the parameters of the finite helical axes (FHA) [8, 9] for discrete sampling ranges of the movements: i.e. orientation (n), position (p), shift (s) along and rotation (θ) about the estimated helical axis. This FHA-approach was chosen instead of the Euler/Cardan angles method for methodological reasons [10]. The anatomical data were used for the definition of local bone embedded co-ordinate systems. To analyze the 3D-arthrokinematics of the atlanto-axial joints, the finite helical axis was related to a co-ordinate system based on the transverse processes and the anterior tubercle of C1 and the transverse processes and centre of the anterior corpus of C2 (fig.1). Finite helical angles (θ_1, θ_2, θ_3) were derived by decomposing the rotation vector ($n\theta$) according to the defined local frame. Characteristics of motion coupling patterns were studied by comparing the associated rotational components at the moment of peak axial rotation or lateral bending (= main motion). Patterns were labeled ipsi-or contra-lateral according to the signs of the rotations. If the coupled motion was less or equal to 1° it was concluded that no coupling was present. The results were compared with the data from cross-correlation, ratio and phase shift calculations between main and coupled motions for each specimen. It can be demonstrated that the cosine of the shift angle between two sinusoidal signals equals their cross-correlation coefficient [11].

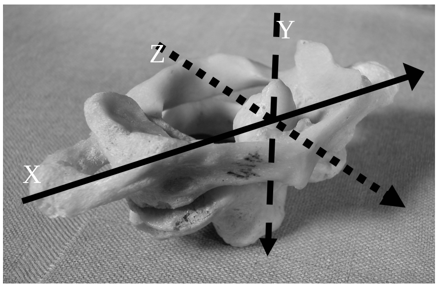
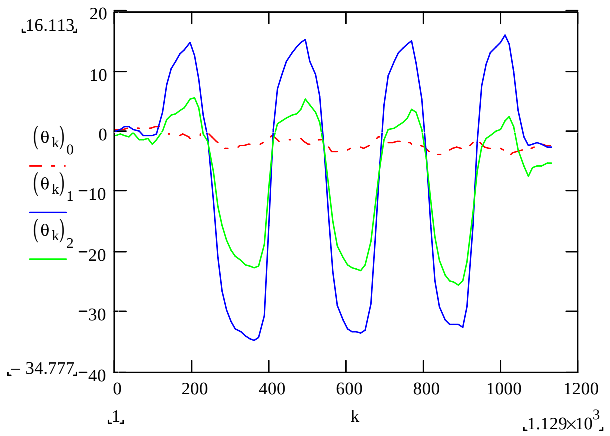


Figure 1. local coordinate frame of atlanto-axial joint

III. Results

The results indicate that, although the segmental manual mobilizations are induced as so called planar motion, the arthrokinematic analysis reflects the 3-dimensional aspects. These 3D-aspects were analyzed in terms of coupled motion patterns between axial rotation and lateral bending and termed ipsi- or contra-lateral, according to the sign of the coupled motion relative to the main motion.



Cor = 0.936 ratio = 0.624

Figure 2. results of axial rotation mobilization of specimen 5

A. *Axial rotation*

The results of the axial rotation movements of the specimens show the combined helical angles for the atlanto-axial (C1-C2) segments (figure 2, table I). At this motion segment, the results of the rotation around the Y-axis during axial rotation generate the largest segmental rotational movement in the upper cervical spine (48° ± 8°). During the axial rotation movement, the main rotation around the Y-axis $(\theta_k)_1$ was combined with a contra-lateral rotation around the Z-axis $(\theta_k)_2$ in seven out of ten specimens.

The results of the cross-correlation analysis confirm these observations. Seven out of ten specimens have a negative cross-correlation coefficient indicating a contra-lateral coupling pattern between the main axial rotation and the coupled lateral bending motion. The mean cross-correlation of these specimens is -0,758 (± 0,164). The cross-correlation coefficient for the ipsi-lateral coupling specimens is 0,888 (± 0,121).

The mean ratio was 0,442 ± 0,222 and 0,432 ± 0,169 for the contra-lateral and ipsi-lateral coupling specimens respectively. This indicates that during axial rotation mobilization the range of coupled lateral bending motion is somewhat less than half the main axial rotation motion.

The phase shift results indicate that there is generally a delay between the main and coupled motion (resp. 37.8° for the contra-lateral coupling and 24.7° for the ipsi-lateral group). The standard deviation of this shift parameter however, indicates large differences in the amount of the delay for the individual specimens.

The results of the fresh specimen (spec.10) did not differ significantly from the results of the embalmed ones.

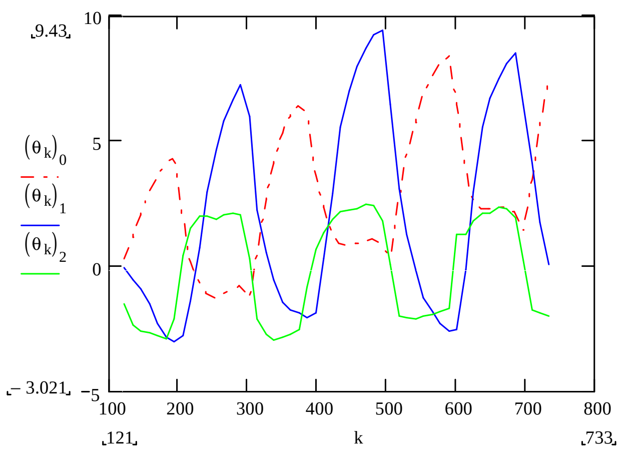
B. *Lateral bending*

The manually induced lateral bending movement is represented by $(\theta_k)_2$. Based on the analysis of peak rotations at the atlanto-axial level, no systematic coupling pattern around the Y-axis $(\theta_k)_1$ could be observed during the manually induced lateral bending mobilization (column 2 table I). And the range of motion was mostly small around all axes. In eight specimens, the coupled motion components around the Y-axis $(\theta_k)_1$ exceeded the main motion around the Z-axis $(\theta_k)_2$. At the atlanto-axial motion segment, the fresh specimen presented a contra-lateral coupling between the main motion around the Z-axis and the coupled motion around the Y-axis. This coupling pattern was observed only once in the embalmed group. Ranges of the main and coupled motion components were significantly different from the embalmed group.

However, using the cross-correlation coefficient, patterns of coupled motion could be determined as ipsi-lateral in seven cases and contra-lateral in the three others. The ipsi-lateral coupling specimens showed a higher cross-correlation value of 0,869 (± 0,142) with respect to the contra-lateral coupling specimens, which showed a cross-correlation coefficient value of -0,686 (± 0,253).

The mean ratio was 2,686 (± 1,562) and 1,978 (± 0,887) for the ipsi-lateral and contra-lateral coupling specimens respectively. These results indicate larger coupled axial rotation components, compared to the main lateral bending components.

The analysis reveals mean phase shifts values between lateral bending and axial rotation, ranging between 7.25° and 65,42°.



Cor = 0.771 ratio = 0.21

Figure 3. results of lateral bending mobilization of specimen 3

AXIAL ROTATION C1-C2	coupling pattern peak rot/lat bend	cross-correlation	coupling pattern	ratio	phase shift in °
spec 1	contra	-0,558	contra	0,295	56,08
spec 2	contra	-0,869	contra	0,581	29,66
spec 3	ipsi	0,750	ipsi	0,369	41,41
spec 4	contra	-0,987	contra	0,332	9,25
spec 5	ipsi	0,936	ipsi	0,624	20,61
spec 6	(ipsi)	0,978	ipsi	0,304	12,04
spec 7	contra	-0,649	contra	0,268	49,53
spec 8	contra	-0,667	contra	0,881	48,16
spec 9	contra	-0,659	contra	0,298	48,78
spec 10	*contra*	*-0,920*	*contra*	*0,439*	23,07
mean		-0,192		0,439	78,95
sd		0,822		0,210	34,71
mean -		**-0,758**	**n=7**	**0,442**	**37,79**
sd -		0,164		0,222	17,31
mean +		**0,888**	**n=3**	**0,432**	**24,69**
sd +		0,121		0,169	15,10
LATERAL BENDING C1-C2	**coupling pattern peak rot/lat bend**	**cross-correlation**	**coupling pattern**	**ratio**	**phase shift in °**
spec 1	no	-0,416	contra	1,753	65,42
spec 2	no	0,869	ipsi	1,438	29,66
spec 3	no	0,771	ipsi	4,761	39,56
spec 4	no	-0,918	contra	2,956	23,36
spec 5	no	0,918	ipsi	3,702	23,36
spec 6	ipsi	0,992	ipsi	3,331	7,25
spec 7	contra	-0,723	contra	1,226	43,70
spec 8	changing	0,965	ipsi	0,550	15,20
spec 9	ipsi	0,971	ipsi	3,398	13,83
spec 10	*contra*	*0,597*	*ipsi*	*4;587*	53,34
mean		0,381		2,568	67,60
sd		0,813		1,384	35,65
mean -		**-0,686**	**n=3**	**1,978**	**44,16**
sd -		0,253		0,887	21,03
mean +		**0,869**	**n=7**	**2,686**	**32,48**
sd +		0,142		1,562	16,17

TABLE I. RESULTS OF AXIAL ROTATION AND LATERAL BENDING COUPLING PATTERNS

IV. DISCUSSION AND CONCLUSION

Several authors [12, 13] have reported ranges between 45° and 88,5° for active axial rotation at the C1-C2 motion segment from in-vivo studies using stereo-photogrammetric techniques. In this in vitro study, the mean range of axial rotation motion is situated in the lower range of the values emanating from the in vivo studies. Taking into account the age of the specimens, this can be regarded as normal.

The calculation of the ratio between the main and coupled motion components offers an objective interpretation of the relative importance of the coupled motion. This coupled lateral bending reached almost half of the mean axial rotation motion at the atlanto-axial level in the contra-lateral coupling group, and was slightly smaller in the specimens presenting ipsi-lateral coupling patterns. This shows that during planar manual mobilization an important coupling of motion occurs which has to be taken into account.

Panjabi et al.[2] have reported combined movements in the upper cervical spine in different positions, applying pure moments of force. These authors equally registered the largest angular displacements in the axial rotation component and found them to be contra-laterally coupled with lateral bending in the atlanto-axial joint.

The use of cross-correlation coefficient showed to be a more useful and objective tool to analyze patterns of coupled motion, especially when the patterns are less clear to analyze like in lateral bending mobilization of the atlanto-axial joint. Using the cross-correlation coefficient an ipsi-lateral coupling pattern was revealed in 7 out of 10 cases and a contra-lateral pattern in the three others. The large standard deviations of the ratio are indicative for large inter individual differences, but the overall values depict the generally larger coupled axial rotation over the main lateral bending component.

Phase shifts are generally present in all specimens, but the results show large inter-individual variations.

These results also support the idea that axial rotation is the dominant movement in the atlanto-axial joint.

The presented set-up and analysis approach offers opportunities for future study of manually performed complex movements in the cervical spine with specific clinical relevance. The use of cross-correlation, ratio and shift coefficients may also be relevant for further in vivo research of coupled motion in the upper cervical spine.

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