Reproducibility of global three-dimensional motion during manual atlanto-axial rotation mobilization: an *in vitro* study

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The reproducibility of the three-dimensional (3D) kinematic aspects of motion coupling patterns during manual mobilizing techniques is still a debatable matter. The present *in vitro* study analysed segmental 3D motion of the atlanto-axial joint during manual axial rotation mobilization. Twenty fresh frozen human cervical specimens were studied in a test-retest situation with two examiners. The specimens were manually mobilized using three different techniques: (1) a regional mobilization technique of the cervical spine; (2) a segmental mobilization technique of the atlas with manual fixation of the axis; and (3) a segmental mobilization of the atlas on the axis applying a locking technique. Segmental atlanto-axial kinematics was registered with a Zebris CMS-20 ultrasound-based tracking system. The Euclidian norm was used as a representation of overall 3D motion. The results indicated good reproducibility (mean intraclass correlation coefficient, ICC: 0.87). Intraobserver reproducibility was slightly higher (mean ICC: 0.91; range: 0.76–0.99) than interobserver reproducibility (mean ICC: 0.85; range: 0.56–0.98) ($P < 0.05$). The total range of motion expressed as the Euclidean norm of 3D motion components was a parameter with good reproducibility in the study of segmental kinematics of manual atlanto-axial mobilization. Although previous studies have demonstrated poor inter-rater reliability of manual examination and mobilization of segmental motion components, the results of the present study shed a new and more positive light on the reproducibility of techniques for manual mobilization of the upper cervical spine.

Keywords: Atlas, Axial rotation, Axis, Euclidean norm, *In vitro*, Manual mobilization, Reliability reproducibility

Very few studies have examined the kinematics of spinal manipulative therapy. Some authors have focused on the global range of motion of the cervical spine during high-velocity thrust techniques.^{1–3} Even the reproducibility of the clinical manual examination and mobilization of joints in general and of the spine in particular is a much debated subject, and substantial evidence is rather sparse and exemplary. Some authors found strong variability between the ratings of cervical intervertebral mobility among examiners, whereas others have indicated that the combination of several regional and segmental examination techniques can lead to an adequate and reproducible differentiation between patients and controls.^{4–8}

In recent publications, investigators have sometimes still relied on two-dimensional methods of spinal motion analysis. It is generally accepted that a three-dimensional (3D) approach offers a far more realistic

representation.⁹ However, the use of surface markers seems to be a major barrier for *in vivo* 3D segmental motion evaluation by video-analysis due to uncontrollable (skin) artifacts.¹⁰ Although offering a unique situation for investigating 3D segmental movements *in vivo*, the use of Kirschner pins or other percutaneous instrumentation requires invasive procedures and is seldom approved by ethical committees.

To combine a 3D kinematics approach with a segmental motion analysis, most authors have proposed *in vitro* laboratory set-ups.^{11–13} Although these studies have used well-controlled moments of force to induce movements and have even attempted to simulate manual mobilizing techniques, thus eliciting the possible specific effects of such interventions,¹⁴ the authors did not provide information on the reproducibility of the investigated kinematic aspects.

The quantification of kinematics is often limited to the description of ranges of motion and of the direction of the coupled motion component with reference to the main motion. Motion coupling

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patterns are generally described as ipsi- or contralateral and have also been demonstrated *in vitro*.¹² These patterns, however, may be very complex and should be studied in a more complete way by analysing several parameters describing different aspects of this kinematic behavior.^{15,16}

Several factors create a need for more specific research. The first is the previously mentioned lack of evidence on the global and segmental kinematics of orthopedic manual examination and mobilization techniques and the risks and possible benefits related to this. Second, there is a lack of information on the complex coupling patterns, although they are often referred to in chiropractic, manual orthopedic, or osteopathic practice. Moreover, there is contradictory information on the reproducibility of manual intervention in general but at the spinal level especially, thereby creating a need for more specific research. So far, little evidence has been presented to help therapists understand what really happens during manual mobilization at the level of the cervical spine and especially at the atlanto-axial joint, which is generally considered a vulnerable region for manipulative therapy.^{14–18} Most therapeutic strategies are built on mechanical concepts of motion coupling derived from general anatomical joint models and they often ignore anatomical variability. Moreover, the specific effects of therapist specific variation in techniques have been ignored.

It has been demonstrated recently that a combination of an *in vitro* approach using an ultrasound device for continuous motion registration with manual applied mobilization techniques offers the possibility of combining the strengths of an adequate 3D analysis system with performance of a continuous registration of movements in a test–retest situation with two observers.^{17–19} At present, this is not possible in an *in vivo* approach.

A previous study using this approach demonstrated that the main axial rotation motion component shows adequate intraobserver reproducibility during an axial rotation mobilization of the atlanto-axial spinal motion segment.¹⁹ However, strong variability was demonstrated between the results of different examiners, and the reproducibility of kinematic parameters, including the range of motion of the coupled motion components, the cross-correlation, the ratio, and the phase shift, was insufficient overall. The relevance of manual examination and mobilization techniques for decision making in diagnostic or therapeutic settings should be studied in a more clinical context taking into consideration these basic results. To date, no adequate *in vivo* techniques exist to analyse spinal segmental kinematics during manual mobilization.

The analysis of motion reproducibility can be considered an aspect of the study of reliability

focusing on the closeness of agreement among repeated measurements of a variable made under the same operating conditions over a period of time, or by different people. The single goal of the present study was to analyse the reproducibility of the intervertebral 3D motion of manual regional and segmental axial mobilization techniques of the atlanto-axial joint from a new point of view by considering global 3D motion expressed as the Euclidean norm of the combined 3D motion components instead of analysing each motion component separately. The Euclidean norm is defined as the root of the sum of the squared values of the ranges of each separate motion component. This study analyses previous data¹⁹ from a new point of view.

Methods

Twenty fresh frozen human spinal specimens were included in the study: nine specimens were from male and 11 were from female subjects. Each specimen included the occiput, the cervical segments, and the first two thoracic vertebrae. The mean age of the specimens was 80 years (± 11 years) with a range from 59 to 97 years.

Room temperature was controlled between 15 and 20°C, and humidity was above 60% to prevent dehydration of the specimens during the test procedure. An adapted Zebris CMS-20 (Zebris Medical GmbH, Germany) ultrasound-based motion tracking system was used. The accuracy of the system has been demonstrated in previous studies indicating an error of less than 0.2° with each of the three motion components.¹⁹

In all specimens, the skin, subcutaneous tissue, and muscles were dissected, leaving the muscular insertions and ligaments intact. This dissection is necessary to allow full movement and to prevent uncontrolled coupled motions that might occur due to the fixation of the ultrasound system on the segments. Moreover, the post-mortem biomechanical changes within the muscles might influence the results. It has, however, been demonstrated that the biomechanical properties of the tendons and ligaments do not change due to conservation by freezing.^{20,21}

Specially fabricated fixation tools were inserted in the transverse processes of the atlas and the axis.^{15–17} The transmitters and receivers of the Zebris system were mounted on these fixation tools. A second transmitter of the system was mounted on the occiput for registration of the atlanto-occipital segmental movements. However, in the scope of this paper, only atlanto-axial motion was analysed and reported. The optimal positioning of the device allowing continuous registration of the signals throughout the whole mobilization range was controlled for every specimen before the start of the mobilizations. Fixation pins were drilled cross-linked through the corpus of the

Figure 1 Experimental set-up with fixation of the ultrasound system (A) and mobilization of the specimen in supine position *in vitro* (B).

second thoracic vertebra (T2). The specimen was mounted in a wooden frame by these fixation pins.^{15–17} In this way, the specimen was positioned as if the subject was in a supine position on an examination table (Fig. 1). The preliminary dissection and the optimal positioning of the fixation tools assured free mobility of the cervical spine through the full range of motion in axial rotation, lateral bending, flexion–extension, and combined directions.

In the *in vitro* test situation, each specimen was first mobilized in the transverse plane of the anatomical reference frame through the full range of cervical axial rotation mobility. While the lower thoracic segments are relatively fixed by the weight of the thorax lying on the bed (or in the *in vitro* set-up by fixation in the wooden frame), the head is sustained and turned to the left and right, mobilizing the whole cervical spine (Fig. 2A demo *in vivo*). Second, two segmental mobilization techniques were performed at the level of the atlanto-axial joint. In the first technique, the axis was manually fixed while the atlas was manually rotated to the left and to the right (Fig. 2B demo *in vivo*). This technique was labeled the ‘fixation’ technique in this study. During the second technique, the cervical spine was put in a 3D locking position, combining lateral bending and contralateral

rotation of all inferior cervical segments including the C3-axis level (Fig. 2C demo *in vivo*). In this position, the atlas was mobilized in axial rotation with respect to the axis. This technique was labeled the ‘locking’ technique. All movements were performed three times consecutively starting from the neutral position and performing three consecutive mobilizations to full left and right rotation. Range of motion is defined as the excursion between the most extreme rotation positions within these three repetitions. The rate of mobilizations was decided by the investigators who were free to mobilize the specimens until the end-range positions with an intensity and at a speed to their convenience as to mimic normal variation within the clinical situation. All mobilizations were performed to the end range, and the therapists estimated the applied load to be similar to that which they would use in a well relaxed asymptomatic subject.

Two therapists with an overall clinical experience in orthopedic manual therapy of the spine of more than 10 years performed the three mobilization techniques in a test–retest situation. The test order was assigned randomly for the two investigators. Investigators were blinded from the analysis data of the system during testing. One of the examiners had

Figure 2 *In vivo* demonstration of manual mobilization of the atlanto-axial joint in a clinical situation. (A) Regional mobilization; (B) segmental technique with manual fixation of the axis; (C) segmental technique with combined locking of the lower cervical spine.

Figure 3 Motion coupling patterns during regional axial rotation mobilization (of specimen 1). (A) Examiner 1 test situation; (B) examiner 1 retest situation; (C) examiner 2 test situation; (D) examiner 2 retest situation. k : measurement samples at 20 Hz; x_k : flexion–extension component in degrees; y_k : axial rotation component in degrees (+ maximum and – minimum values); z_k : lateral bending component in degrees.

been familiar with the investigated techniques for many years, while the other usually performed similar but not identical mobilizing techniques and was familiarized with the specific techniques described above before the testing period. Both examiners performed a trial with feedback from the tracking system in a test–retest situation on one specimen to familiarize themselves with the techniques and the experimental set-up.

The angles of movement used in the present analysis are the angles reproduced from the Zebris-Winbiomechanics software® (version 0.2.1; Zebris Medical GmbH, Isny, Germany). A graphical representation as well as a mathematical reconstruction of the calculated angles has been presented previously.^{19,22} The definition of the local reference frames used by the Zebris system is based on three markers: L (left), R (right), and F (front). The points L were chosen on metal markers inserted on the left transverse process of the axis and atlas respectively, the points R were on the right transverse processes, and the point F was central on the anterior side of the corpus of the atlas and the arcus anterior of the axis. Although the International Society of Biomechanics (ISB) provides guidelines for defining the local reference frame for mid-cervical spinal segments, it

does not define standards for local reference frames on the atlas or axis.²³ The bone-embedded reference frames for atlas and axis were described as above and the labeling of the axes was chosen in accordance with the guidelines of the ISB:

The axes are defined as follows:

- x-axis: from right to left transverse process: segmental flexion–extension axis;
- z-axis: from the anterior center of the corpus or arcus perpendicular to the x-axis: segmental lateral bending axis;
- y-axis: perpendicular to the x and z axes: segmental axial rotation axis.

The direction of the z-axis was reversed to create a right-handed orthogonal reference frame. For clarity of the graphical and numerical representation, the sign of the angles around the y-axis was changed. In this way, an axial rotation and a lateral bending to the same side are indicated by the same sign (left and right respectively represented by – and + signs; see Fig. 3).

The range of motion was calculated for the main axial rotation movements as well as for the coupled lateral bending and the flexion–extension components. In the present study, the Euclidean norm was calculated as a mathematical representation of the overall 3D motion. The Euclidean norm is a

Table 1 Descriptive statistics of the Euclidean norm of three different mobilizing techniques for the test and retest situations of two examiners

Euclidean norm (<i>n</i> = 20)			Mean	SEM	SD	Range
Regional	Examiner 1	Test	62.45	2.62	30.35	11.70–82.22
		Retest	63.59	2.87	35.15	12.83–83.63
	Examiner 2	Test	58.28	1.75	17.87	15.04–83.25
		Retest	60.63	1.76	28.24	13.35–83.95
Fixation	Examiner 1	Test	56.33	3.75	31.91	16.76–112.63
		Retest	56.71	0.87	23.22	16.43–98.79
	Examiner 2	Test	51.50	2.41	31.49	10.52–74.00
		Retest	56.63	2.78	31.56	12.45–86.04
Locking	Examiner 1	Test	61.67	2.75	41.26	12.28–83.74
		Retest	64.05	3.28	36.11	14.32–95.26
	Examiner 2	Test	51.50	2.90	31.49	10.52–74.00
		Retest	60.79	2.77	33.92	12.39–82.76

Note: Regional: regional mobilization technique; fixation: fixation mobilization technique; locking: locking mobilization technique; Euclidean norm: squared root of the sum of the squared values of three separate motion components (segmental axial rotation, lateral bending, and flexion-extension component); SEM: standard error of the mean; SD: standard deviation; range: minimum and maximum Euclidean norm values of 20 specimens.

mathematical representation of 3D motion and, as such, cannot be interpreted as a range or degrees of motion.

A Kolmogorov–Smirnov goodness of fit test was performed to control for normal distribution of data within these different parameters, and descriptive statistics were calculated (Table 1). The strength of the correlation between Euclidean norm values in different measurement situations was estimated by the intraclass correlation coefficients (ICC) (SPSS 16.0). An alpha level of <0.05 indicated statistical significance.

Results

Based on the results of the Kolmogorow–Smirnov goodness of fit test, the parameters analysed in this study show no significant deviations from the normal distribution (Table 1). Data from all 20 specimens were analysed.

Correlation between test and retest results and between examiners was performed using parametric statistical techniques. The results of the analyses of the separate motion components have been presented previously.¹⁹ The ICCs (type 3,k) for intraexaminer results and interexaminer comparison of the Euclidean norm are summarized in Table 2. The three different mobilization techniques show similar reproducibility results. All ICC values are statistically significant at the 0.05% level. The mean intraexaminer ICC is 0.91 (range: 0.76–0.99) and the mean interexaminer ICC is 0.85 (range: 0.56–0.88). The standard error of the means varies from 0.87 to 3.74 (mean: 2.54) (Table 1). Figure 3C is indicative of the variability in performance between repeated performances of the mobilization techniques. The shift of the axial rotation component curve can be related to a non-neutral starting position. Such variability has an influence on the reproducibility of the separate motion components.¹⁹ However, based on the results of the present analysis, it can be stated that this

variability does not influence the Euclidean norm in a significant way.

Discussion Reproducibility

Reproducibility of manual and more specifically segmental mobilization techniques remains a debatable matter in the literature. There seems to be a general tendency towards higher intraobserver reliability compared to interobserver results.^{24–32} The present results point somewhat in the same direction. In a recent systematic review of the literature on this topic, higher reproducibility of regional compared to segmental manual mobilizations has been reported.^{33,34} This differs from the findings of the present experiment.

In a previous study analysing the same data, the authors demonstrated that the main axial rotation motion component is the only parameter showing significant intra- and interexaminer reproducibility. Substantial ICC values were demonstrated in regional as well as in segmental techniques.¹⁹ However, the study reported significant differences in intraexaminer reproducibility for the range of

Table 2 Intraexaminer and interexaminer intraclass correlation coefficients for motion coupling parameters of three atlanto-axial mobilizing techniques: ICC (and significance)

Intraobserver reproducibility		
	Examiner 1	Examiner 2
Regional	0.97**	0.99**
Fixation	0.97**	0.80**
Locking	0.95**	0.76**
Interobserver reproducibility		
	Mean	Range
Regional	0.97**	0.95–0.98
Fixation	0.85**	0.74–0.96
Locking	0.75**	0.56–0.94

Note: Numbers represent ICC (3,k) values.

**Significant at 0.01 level.

motion of the coupled motion components, the cross-correlation expressing the concordance between the main axial rotation and the coupled lateral bending component, and the ratio expressing the relative magnitude of the coupled lateral bending. From the results of this previous analysis, it has been demonstrated that one of the therapists, who had been familiar with the techniques for many years, showed higher reproducibility values than the second examiner, who had used similar but slightly different techniques in daily clinical practice. The results tended to indicate that the level of familiarization and experience with the specific technique may play a positive role in the reproducibility of the kinematics. So far, little or no evidence is available on the effect of therapist experience in the clinical assessment of the spine. The analysis of the results of the present study indicates that clinicians can perform similar segmental axial rotation mobilization techniques of the atlanto-axial spine in an *in vivo* situation, inducing similar amounts of overall 3D motion. From previous analysis, it seems that clinicians do this in different ways by combining different degrees and combinations of 3D motion components during repeated mobilizations.¹⁹ As the reproducibility of the main axial rotation component is good, clinicians seem to vary mainly in the combined motion components.

Variability in ranges of the different motion components might be related to the experimental set-up and the variability in defining the local reference frame to which the segmental motion components have been referred. However, it can also be suggested that minor intra- and interindividual variability in technical performance exists, although the reproducibility of the overall 3D motion is good.

Strength and weaknesses of the in vitro approach

Dissection of the specimens was necessary in the present set-up. As a consequence, the present study can at best simulate a clinical situation although it cannot replicate a true physical examination of a patient. The examiners, however, experienced a great similarity with daily clinical practice. According to the examiners, not being hindered by soft tissues and being able to get a good grip may have offered a slight advantage. In future research, use of 3D medical imaging techniques capable of capturing 3D motions may challenge the present results with an *in vivo* approach. At present, the methodology presented in this study offers the only opportunity to perform a continuous 3D kinematic analysis of manually induced motions of the upper cervical spine as used in orthopedic clinical practice.

Segmental atlanto-axial rotation has been reported to range between 45 and 88.5°. In the previous analysis, the authors reported a mean axial rotation range of $48 \pm 8^\circ$ at the atlanto-axial level, which is

situated in the lower range of the *in vivo* references.¹⁶ The age of the specimens is higher than the mean age of people generally consulting for manual therapy. However, taking into account the age of the specimens in this study, the ranges of motion can be regarded as within normal segmental ranges.³⁵ This finding supports the external validity of the present results. So far, no reference data for Euclidean norm values have been reported.

Clinical relevance

In the previous analysis, the authors investigated the reliability of each motion component separately and could not indicate sufficient intra- and interobserver reproducibility.¹⁹ As such, those results supported previous studies indicating low reliability of manual examination and mobilization techniques. The present study, however, analyses the overall 3D motion, combining all three motion components in one parameter – the Euclidean norm – during manual mobilization and, contrary to the previous study, shows a high intra- as well as interobserver reproducibility. This is a new and positive finding indicating that therapists are able to reproduce segmental 3D motions and may apply this in their clinical practice. However, taking into account the results of the first analysis, therapists should realize that seemingly during repeated mobilizations, they use different motion components to do so.

Previous studies showing poor reliability results of regional and segmental clinical examination techniques may need to be reviewed in terms of these new findings and should incorporate all motion components, possibly resulting in a new and more positive view on reliability aspects of orthopedic manual therapy. Manual therapists should be encouraged by the positive results of this reliability study to improve their skills and practices because from this and the previous study, there are indications that reproducibility improves when familiarization with the specific techniques increases.

Conclusions

The intra- and interobserver reproducibility of the global 3D motion as expressed by the Euclidean norm of the separate motion components is very good for regional as well as segmental axial rotation mobilizations as investigated in three different mobilization techniques in this study. Although separate kinematic aspects of motion coupling seem to vary among examiners, the comparison of the results of the present analysis with previous data indicates that the overall 3D motion is a stable parameter. Taking into consideration minor variation in performance expressed in variability in motion components among clinicians, the present results indicate a generally strong agreement in main and overall motion components of regional as well as segmental mobilization techniques of the atlanto-axial joint. All mobilizing techniques investigated

in the present study showed similar levels of reproducibility.

These results should be interpreted in view of the limitations inherent in the present *in vitro* possibilities in analysing 3D kinematics of manually induced motion of the atlanto-axial joint. It cannot be ignored that aspects such as the presence of active muscles responding to passive movement or stabilization, the presence of active neural tissue, and the presence of patient feedback cannot be reproduced in an *in vitro* situation.

This study sheds new light on manual diagnostic and therapeutic techniques by challenging previous reports on low reproducibility in *in vivo* as well as *in vitro* situations.^{4,6,19} Based on the present results, it can be concluded that clinicians are able to reproduce global 3D motions during manual techniques with good accuracy in an *in vitro* situation. The results should encourage orthopedic manual therapists to continuously improve their skills and practices in daily clinical practice and to achieve optimum familiarization with different new and specific therapeutic techniques.

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