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3D kinematic analysis of the atlanto-occipital joints during a regional manual mobilization into flexion-extension: an in vitro study

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ABSTRACT

Background

Few studies have investigated the kinematics of the upper cervical spine during manual mobilization. Some information about rotational movements is available in literature but also translational components must be examined to understand the complex inter-segmental motions. This study aims to describe the amount, trajectories and reliability of atlanto-occipital facet joints displacement during a passive regional flexion-extension mobilization.

Materials and methods

20 fresh frozen human cervical specimens (mean age 81 years, range 59-95 years) were examined in a test-retest setting. Two experienced manual physiotherapists performed the mobilization, while a Zebris CMS20 ultrasound-based motion tracking system was performing a continuous recording.

The amount and trajectories of C0 displacement were calculated along the XYZ axes. Difference between measurements were evaluated with the Friedman two-way ANOVA test. Intra- and inter-rater reliability were estimated through ICC scores.

Results

The mean angular motion in flexion-extension was of 18.7° (SD±6.5°). The mean values of articular facets' displacement were 7 mm (SD±4.1) and 11.5 mm (SD±5.5) for the left and right joint respectively.

The average induced displacement did not significantly differ between testers and test condition (2-way Friedman ANOVA, $p > 0.05$). The results indicate moderate to good reproducibility within and between testers (ICC range 0.63-0.85) ($p < 0.05$) for the total motion, with more variability for the single motion components.

Conclusions

The amount of rotational and translational displacement in the atlanto-occipital joints is variable between and within subjects (left and right side).

When different physiotherapists perform a flexion-extension cervical mobilization, a moderate to good inter-examiner reliability can be reached for the overall motion, but the single motion components appear to be less reproducible and predictable.

These findings may be of high importance to better understand the kinematics of manual mobilizations for the purpose of teaching and practice.

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INTRODUCTION

In manual therapy, joints are assessed and treated relying on the current knowledge about the three-dimensional aspects of their kinematics, however, only limited information is available about the atlanto-occipital joints and how its kinematics is influenced by manual mobilization.

Peculiarities of the flexion-extension motion at C0-C1 level have been described *in vitro* and *in vivo* during passive and active mobilization using various movement analysis methods[1-7]. The average range of motion varies from 3.5° to 12.7° for flexion, from 12.7° to 25° for extension[3,4,5] and from 13° to 30° for the total movement[1,2]. A more recent in vitro laboratory study reported that between 41% and 45% of flexion and 69% to 71% of extension of the upper cervical spine occurs at C0-C1 level[8].

Coupled motions during active flexion-extension of the upper cervical spine have been reported as a mean of 1.6°(SD±1.1°) lateral bending and 2.5° (SD±1.2°) axial rotation during flexion, 1.6°(SD±1.4°) lateral bending and 3.1°(SD±3.9°) axial rotation during extension. The dominant pattern found by the study was of left lateral flexion and right rotation during flexion, right lateral flexion and left rotation during extension[6].

Cattrysse et al.[8] conducted a study on cadaveric specimens, analyzing the three-dimensional kinematics of a segmental spinal mobilization of C0-C1 in flexion-extension and comparing different fixation techniques. The manual fixation of C1 significantly reduced the coupled components on the mobilized segment and at the adjacent C1-C2 joint but did not significantly influence the flexion-extension component compared to a regional mobilization. On the other hand, a locking technique of the underlying cervical vertebrae did not influence associated movements at C0–C1 compared to a regional mobilization. However, it reduced the main motion as well as coupled motions at C1-C2.

Similarly, manual high-velocity low-amplitude (HVLA) rotational thrusts directed at C1-C2 showed induced motion components between 0,3° and 1° at C0-C1 during the thrust[9]. Axial rotation components were nearly equivalent at both levels, with less lateral bending and flexion-extension at the atlanto-occipital joints. For this unintended kinematics of C0-C1 during HVLAs on C1-C2, low intra-and inter-examiner reproducibility indicated high performance variability between and within practioners[10].

Few studies have analyzed, in addition to the overall motion, the displacement of the articular surfaces of the vertebrae. *In vitro* testing of zygapophyseal joints in the lower cervical spine, showed that, without ligamentous constraints, they can be highly mobile, displaying up to 19° of flexion, 14° of extension, 28° of lateral bending, 17° of axial rotation and 9mm of translations[11]. Some information is available also about C1-C2 joints, from *in vivo* three-dimensional CT studies aimed to investigate the limits of normal movement in children[12], or children and adults[13]. These studies found a wide contact loss between the facet joints during axial rotation (from 70% to 78% on average). A similar study on adults estimated a contact loss between 6.16 and 8.68mm[14].

A 2015 study by *Buzzatti et al.*[15] was the first to calculate the displacement of the atlantoaxial facet joints in cadaveric specimens during a manual mobilization using an ultrasound-based motion tracking system. To the best of the authors' knowledge, no such study has been performed on the atlanto-occipital joints.

The purpose of the present study is to investigate a continuous recording of the three-dimensional aspects of manual flexion–extension mobilization by analyzing the displacement of the articular facets at the atlanto-occipital junction in a test-retest situation with two observers, within an in vitro approach.

MATERIALS AND METHODS

Specimens

Twenty fresh human spinal specimens (11 females and 9 males with a mean age of 81 years, range 59-95 years), gathered from a body donation program and conserved by freezing, were included in this study. Each specimen consisted of the head, the cervical vertebrae and the first 2 thoracic vertebrae. The room temperature was set between 15° and 20° C and humidity above 60% to prevent dehydration of the specimens during the study.

Instruments

An adapted Zebris CMS20 ultrasound-based motion tracking system (Zebris Medical GmbH, Germany) was used in this study.

This device is based on the travel time measurement of ultrasonic pulses transmitted by miniature transmitters (markers) to the three microphones built into the receiving sensor (antenna). The 3D coordinates of the ultrasonic markers can be recorded with an overall scanning rate of 200 measurements per second. Angles of rotation between the transmitters and the receiver are calculated in the Zebris Winbiomechanics software® (version 0.2.7, Zebris Medical GmbH, Germany). The accuracy of the system has been reported previously, demonstrating an angular accuracy of less than 0.1° for the main motion component and of 0.2° for the coupled components[16].

Methods

An accurate dissection was performed in advance to remove skin, subcutaneous tissue, and muscles, preserving bony tissues, muscular insertions, and ligaments. It has been demonstrated that the biomechanical properties of tendons and ligaments do not change due to conservation by freezing[17,18]. This dissection procedure was necessary to prevent data distortion that might occur because of the fixation of the motion tracking system on soft tissues.

Specially fabricated fixation pins were used in order to rigidly fix the Zebris system transmitters and receiver. The antenna was fixed on the left transverse process of the atlas while the two transmitters were fixed on the left transverse process of the axis and laterally on the cranium **(FIG.1)**. Optimal positioning of the device was controlled for every specimen before starting to mobilize it.

FIGURE 1. Experimental set-up: specimen in supine position with the Zebris system.

Metal reference markers were inserted in the cranium (one on the external occipital protuberance and one on the most caudal point of each mastoid process), in the atlas (left and right transverse processes and anterior tubercle) and in the axis (left and right transverse processes and central part of the anterior surface of the vertebral body), so every segment had a left (L), right (R), and central (F) anatomical marker. By digitizing these markers, the Zebris software defined three local reference frames and was able to analyze the kinematics between C0-C1 and C1-C2.
The corpus of the second thoracic vertebra was fixed to a wooden frame by fixation pins and the head simply laid on a headrest. In this way, the specimen was positioned as if the subject was in a supine position on an examination table. Preliminary dissection and positioning of the fixation tools assured free mobility of the cervical spine through the full range of motion.

A set of three consecutive regional cervical mobilizations into flexion and extension was performed two times on each specimen by two examiners in a random order. The technique was performed by two physiotherapists with more than 10 years of experience in orthopedic manual therapy. They were allowed to practice with a specimen before the experiment in order to get more confident with the experimental setting and they were blinded to the data collection from the system and the subsequent analysis.

After the performance of the technique, the system was able to compute rotational movements of the segments. To calculate the displacement of the joints, as the system did not have data about the 3D morphology of the C1 and C0 articular facets, a two-step approach was adopted.

Using a 3D digitizer (3D-Microscribe® Immersion Corporation, USA) the metal reference markers on the specimen were digitized. Subsequently, the specimen was further dissected and segmented, allowing digitization of previously inaccessible anatomical landmarks. The coordinates for the occipital condyles and the superior facets of the atlas were recalculated into the general reference frame by mathematical transformation and a bone-embedded local reference frame was constructed to analyze 3D-joint kinematics. In particular, the center of the facets of C0 condyles was chosen as a reference to calculate joint displacement.

The GeoGebra© (v. 5.0 Beta, International GeoGebra Institute) geometry software was utilized to recalculate the 3D-Digitizer's coordinates in the Zebris reference system in order to compute the continuous displacement of the articular surfaces of the joints during the kinematic recording.

The resulting output from the Zebris software was processed using Mathcad© professional software (v15, Parametric Technology Corporation, USA). This allowed calculating the displacement along the three axes of the reference frame during the whole movement. To determine the trajectories of the displacement during every mobilization, flexion and extension were considered separately employing Mathcad© graphs.

The International Society of Biomechanics does not provide specific guidelines for defining a local reference frame in the upper cervical spine, hence the axis labels were chosen in accordance with ISB guidelines for the mid-cervical spinal segments[19]:

- X-axis: from right to left transverse or mastoid process (segmental flexion–extension axis).
- Z-axis: from the anterior center of the arcus or external occipital protuberance perpendicular to the x-axis (segmental lateral bending axis).
- Y-axis: perpendicular to the x and z axes (segmental axial rotation axis).

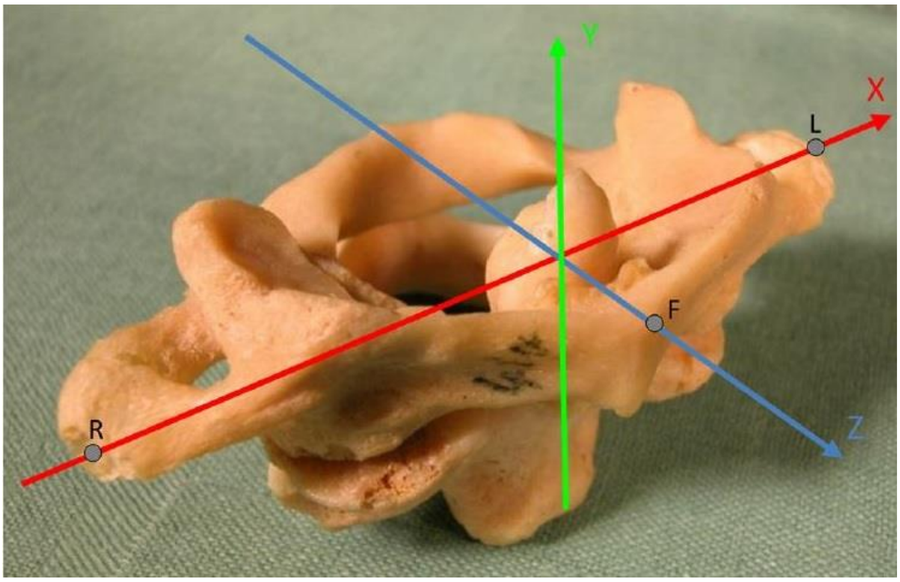

FIGURE 2. Demonstration of the three axes on C1.

Statistical analysis

The SPSS software (version 23.0, International Business Machines Corporation) was used to make all statistical calculations.

An outlier labeling rule based on Interquartile Range with a 2.2 multiplier[20] was employed in conjunction with histograms and Q-Q plots to detect outliers.

Descriptive statistics were used to summarize displacement (flexion+extension) data for X, Y and Z axes and NORM values. In addition, a Shapiro-Wilk test was performed to ensure that assumptions of a normal distribution of data were met

Then, a Friedman two-way ANOVA was chosen to compare the different means of the four records and to highlight differences.

Intra-class correlation coefficients (ICCs) were calculated to investigate the intra-examiner (T1 vs RT1, T2 vs RT2) and inter-examiner (T1 vs T2, RT1 vs RT2, T1 vs RT2, T2 vs RT1) reliability for every component of the induced displacement. The calculation was based on absolute agreement in a two-way random-effects model.

Trajectories

After the analysis of the whole mobilization, flexion and extension were considered separately with the aim of examining the trajectory of the center of the articular surfaces of the occiput.

The start and the end of flexion and extension were determined with Mathcad© graphs. A curve for the angular displacement was plotted in a Cartesian plane, where the time was represented on the absciss axis and the displacement on the ordinate axis. Positive values of the ordinate stood for flexion and negative values for extension.

The displacement of the center of the occipital articular facets was analyzed according to the previous definition of the axes in our reference system:

- X-axis: right or left displacement
- Y-axis: superior or inferior displacement
- Z-axis: anterior or posterior displacement

RESULTS

One specimen was excluded from this study because of the presence of a bony junction that prevented motion between C0 and C1.

Six records out of 76 were excluded from the analysis because they were detected as outliers representing measurement errors.

Descriptive statistics

Descriptive statistics for the angular motion were calculated first **(TABLE 1).**

The mean rotation around the X-axis (flexion-extension) was 18.7° (SD±6.5°), the mean rotation around the Y-axis (axial rotation) was 11.6° (SD±6.5°) and the mean rotation around the Z-axis (lateral bending) was 9.08° (SD±5.26°).

TABLE 1. Angular motion

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Flexion-Extension	70	29.8	4.9	34.7	18.4	6.4
Axial rotation	70	30.5	1.4	31.9	11.6	6.5
Lateral bending	70	21.9	1.3	23.2	9.1	5.2

For the facet joint displacement, descriptive statistics were calculated for the two sides **(TABLE 2)**.

For the left joint, the mean displacement was of 2.6 mm (SD±1.9) along the X-axis, 4.6 mm (SD±3.4) along the Y-axis, 3.6 mm (SD±3.0) along the Z-axis, with a Norm of 7.0 mm (SD±4.1).

For the right joint, the mean displacement was of 3.0 (SD±2.5) along the X-axis, 5.7 (SD±3.6) along the Y-axis, 8.2 (SD±5.6), along the Z-axis, with a Norm value of 11.5 mm (SD±5.5).

TABLE 2. Displacement – Descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation
X Left Displacement	70	0.35	11.74	2.62	1.98
X Right Displacement	70	0.36	15.83	3.08	2.58
Y Left Displacement	70	0.24	16.65	4.64	3.47
Y Right Displacement	70	1.12	20.73	5.74	3.62
Z Left Displacement	70	0.36	12.44	3.65	3.08
Z Right Displacement	70	1.01	28.17	8.29	5.65
NORM Left	70	0.80	17.01	7.07	4.15
NORM Right	70	2.60	31.15	11.50	5.52

X: Medio-lateral displacement (Flexion-Extension axis), **Y:** Caudo-cranial displacement (Axial rotation axis), **Z**: Postero-anterior displacement (Lateral Bending axis), **Norm:** Resultant of the three axes, **Left:** Left facet, **Right:** Right facet.

Test for normality and differences between records

In this test-retest setup, the motion was recorded four times for each specimen, thus there were a first test made by tester 1 (T1), a re-test made by tester 1 (RT1), a first test made by tester 2 (T1) and a re-test made10 by tester 2 (RT2).

Normality of the distribution was checked for each component of motion (X, Y, Z and Norm), under each condition (T1, RT1, T2, RT1) and for each side (Left and Right). According to the more sensitive Shapiro-Wilk test, the distribution of data was not normal for approximately one-third of the 32 tested variables.

Since the assumption of normality was violated, a Friedman two-way ANOVA by ranks was performed. This test did not show statistically significant differences between the four Test conditions ($p > 0.05$) **(TABLE 3)**.

TABLE 3. Friedman two-way ANOVA

	X Left	**X Right**	**Y Left**	**Y Right**	**Z Left**	**Z Right**	**Norm Left**	**Norm Right**
$\chi 2$	2.82	2.14	6.77	1.97	0.6	0.94	2.14	6.42
Sig.	0.44	0.59	0.57	0.91	0.07	0.83	0.57	0.09

$\chi 2$: Chi-square, **Sig**.: Significativity, **X**: Medio-lateral displacement (Flexion-Extension axis), **Y:** Caudo-cranial displacement (Axial rotation axis), **Z**: Postero-anterior displacement (Lateral Bending axis), **Norm:** Resultant of the three axes, **Left:** Left facet, **Right:** Right facet.

Kendall’s W was obtained as a measure of effect size for the Friedman test[21], and its value was small (< 0.2) under all the four conditions. A post-hoc power analysis was conducted with the G*Power software[22], showing a statistical power ranging from 0.05 to 0.63.

ICC

The values of Intraclass Correlation Coefficient were interpreted according to the following classification: less than 0.5: poor, between 0.5 and 0.75: moderate, between 0.75 and 0.9: good, more than 0.9: excellent[23].

Considering the intra-rater reliability **(TABLE 4),** tester 1 reached statistical significance in 6 comparisons out of 9, with a moderate to good correlation between measures. The highest ICC value was displayed for the medio-lateral component (along the X-axis) at the left joint. Tester 2 reached statistical significance in 3 comparisons, with moderate to good reliability. The highest ICC values was displayed for the Left Norm component.

Considering the inter-rater reliability **(TABLE 5)**, statistical significance was reached in 14 out of 32 comparisons, with significant ICC values from moderate to good.

The agreement between testers for the Norm component (Left and Right) was significant in 6 out of 8 comparisons and ranged from moderate to good.

Looking at the single motion components, the posterior-anterior translation along the Z-axis was significantly reproducible in 4 out of 8 cases and displayed a moderate to good correlation, while ICCs for the X and Y components were not statistically significant in the majority of comparisons.

TABLE 4. ICC – Intra-rater

Comparison	X Left	X Right	Y Left	Y Right	Z Left	Z Right	Norm Left	Norm Right
T1 – RT1	**0.79***	**0.74***	0.59	**0.72***	0.44	**0.77***	**0.73***	**0.63***
T2 – RT2	**0.65***	0.46	0.54	0.13	**0.6***	0.27	**0.8***	0.11

X: Medio-lateral displacement (Flexion-Extension axis), **Y:** Caudo-cranial displacement (Axial rotation axis), **Z:** Postero-anterior displacement (Lateral Bending axis), **Norm:** Resultant of the three axes, **Left:** Left facet, **Right:** Right facet, ***:** p <0.05

TABLE 5. ICC – Inter-rater

Comparison	X Left	X Right	Y Left	Y Right	Z Left	Z Right	Norm Left	Norm Right
T1 – T2	**0.66***	**0.66***	**0.62***	**0.5***	0.39	0.25	**0.73***	**0.63***
RT1 – RT2	0.27	0.19	0.23	0	**0.71***	**0.73***	**0.86***	**0.87***
T1 – RT2	0.06	0.23	0.46	0	**0.85***	**0.63***	**0.63***	**0.69***
RT1 – T2	**0.64***	0.61	0.57	0	0.37	0.4	0.4	0.59

X: Medio-lateral displacement (Flexion-Extension axis), **Y:** Caudo-cranial displacement (Axial rotation axis), **Z:** Postero-anterior displacement (Lateral Bending axis), **Norm:** Resultant of the three axes, **Left:** Left facet, **Right:** Right facet, ***:** $p < 0.05$

Trajectories

Trajectories along every axis were analyzed separately for flexion and extension, considering if the tendency was positive or negative and if there were changes of direction during the movement **(FIG.3)**.

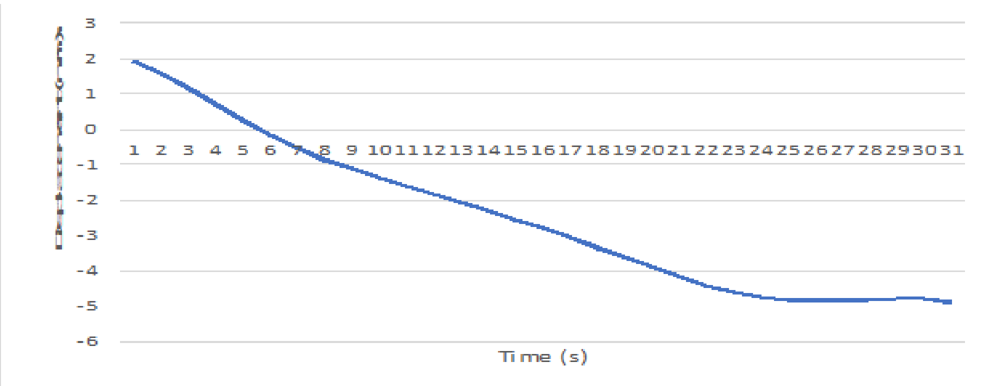

FIGURE 3. A negative trajectory.

Absciss axis: time, **Ordinate axis:** displacement.

During flexion, the left facet moved rightward in 54.3% of cases, superiorly in 62.9% and posteriorly in 61.4%. The right facet moved rightward in 51.3% of cases, inferiorly in 58.6% and posteriorly in 58.6% **(TABLE 6)**.

During extension, the left faced moved rightward in the 54.3% of cases, inferiorly in 72.9% and in 50% anteriorly and in 50% posteriorly. The right facet moved rightward in 71.4% of cases, inferiorly in 58.6% and posteriorly in 58.6% **(TABLE 7)**.

TABLE 6. Trajectory tendency during flexion

Trajectory	X Left	Y Left	Z Left	X Right	Y Right	Z Right
Positive	**54.3%**	**62.9%**	38.6%	**51.4%**	41.4%	41.4%
Negative	45.7%	37.1%	**61.4%**	48.6%	**58.6%**	**58.6%**

X: Right/Left displacement, **Y:** Superior/inferior displacement, **Z**: Posterior/anterior displacement, **Left:** Left facet, **Right:** Right facet, **Positive: right**/superior/anterior displacement, **Negative:** left/inferior/posterior displacement.

TABLE 7. Trajectory tendency during extension

Trajectory	X Left	Y Left	Z Left	X Right	Y Right	Z Right
Positive	***54.3%***	*27.1%*	*50%*	***71.4%***	*41.4%*	*41.4%*
Negative	*45.7%*	***72.9%***	*50%*	*28.6%*	***58.6%***	***58.6***

X: Right/Left displacement, **Y:** Superior/inferior displacement, **Z**: Posterior/anterior displacement, **Left:** Left facet, **Right:** Right facet, **Positive: right**/superior/anterior displacement, **Negative:** left/inferior/posterior displacement.

DISCUSSION

The present study aimed to investigate the three-dimensional kinematics of the atlanto-occipital joints during a manual mobilization. Displacement of the left and right occipital condyle was analyzed based on a local bone embedded reference frame. Being based on local anatomical landmarks, this system of reference is specimen-specific and it does not necessarily coincide with a general reference frame.

As a neutral standardized starting position was not established, the analysis regarding the amount of displacement was performed taking into account the whole flexion-extension mobilization. Flexion and extension were considered separately only for the purpose of determining trajectories of motion.

The recorded angular motion in flexion-extension was, on average, lower than that reported by other studies[2,4,5], and the axial rotation and lateral bending components were generally greater[6], but it has to be noted that all the motion components varied substantially between specimens. These differences may be due refrence frame chosen for this study (functional anatomical versus local bone embedded).

The combined displacement was calculated along each of the three axes of the local reference frames. Moreover, the Euclidean Norm value was derived from the distance between the starting and the end point of the movement, defined by their XYZ coordinates. This is an absolute value which can be used to better interpret and compare the overall magnitude of the 3D motion.

The overall mean displacement differed slightly for the left and right joint, probably due to some specimens which displayed higher displacement on the right. However, this is not surprising because left-right asymmetry and anatomical variants are well documented throughout the cervical spine[24,25].

Absolute displacement was evaluated without considering the initial distance between the two articular surfaces of C0 and C1, so nothing is known about the final position of C0 relative to C1. Future studies could address this issue by calculating that distance and adding it to the amount of displacement.

The more relevant differences were observed for the overall motion of the right joint, with the displacement during the retest by Tester 2 (RT2) displaying the larger mean and standard deviation. Given that the 2-way analysis of variance did not show statistically significant differences between the mean displacement under the four test-retest conditions, this may mean that the two testers were able to induce approximately the same amount of motion at the considered level. However, the sample size and/or the magnitude of the effect size might be another reason for not having found statistically significant values.

The Intraclass Correlation Coefficient offered an indication of the intra-rater and inter-rater reproducibility. Tester 1 showed a moderate to good reliability between the two test situations for most of the motion components, while Tester 2 had a higher ICC value (0.8) for the overall motion of the left facet, but without reaching statistical significance for any motion component of the right articular facet.

Coming to inter-rater reliability, there was a moderate to good reproducibility of the overall motion at the left and right joint, while the correlation was much lower for the single motion components.

The reproducibility of manual techniques was investigated in terms of induced displacement, applied force and diagnostic reliability by many studies conducted on the spine and other joints.

Generally, there is a tendency for intra-examiners reliability to be higher than between different examiners[26–28]. Also, motion assessment in the spine was reported by a systematic review to be more reproducible for regional compared to segmental mobilizations[28].

The role played by the examiner’s experience is not well known. However, some studies suggest that different levels of familiarisation with the specific technique may influence its reproducibility in a test-retest situation[10,15,16,30]. This may help to explain the different intra-examiner reliability scores for the two testers, both experienced physiotherapists. A study including more than two examiners with different levels of expertise could be necessary to generalize these findings.

The trajectory analysis was performed after having considered the overall motion and its results were considered aside from the main displacement analysis.

For what concerns the left occipital condyle, only the inferior displacement during extension was present in more than 70% of cases. The main variability was observed for the anterior-posterior displacement during extension.

The right occipital condyle moved rightward during extension in more than 70% of cases. The main variability was observed for the medio-lateral displacement during flexion.

For both sides and along every axis, the majority of trajectories showed an inversion at the end of the motion, after the facet's center reached the maximum displacement in that direction **(FIG.4)**. Also, during extension, in some cases a superior or anterior trajectory along the Y or Z axis was followed before it turned inferior and posterior. However, the magnitude of these inversions was superior to one millimeter only in few cases and in general it did not affect the overall trajectory direction.

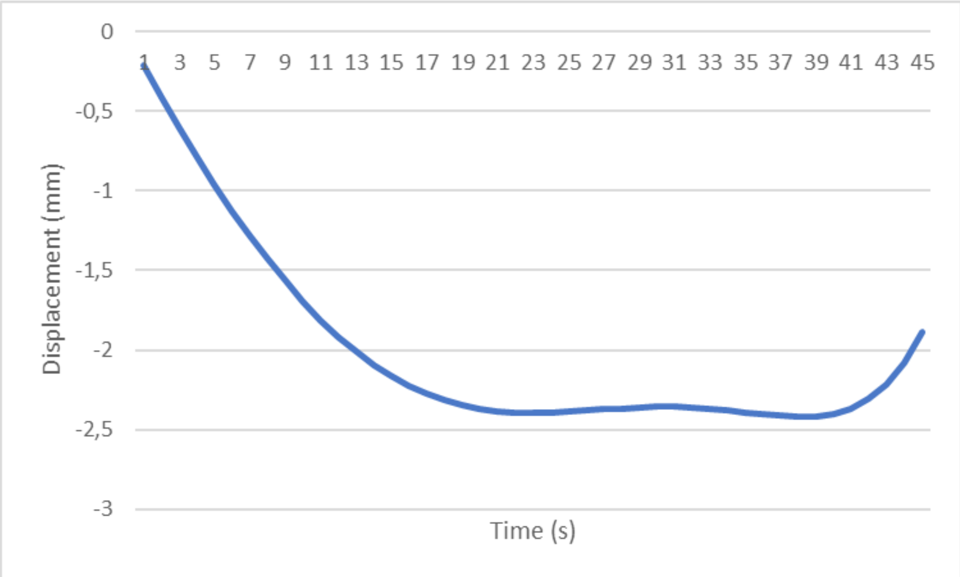

FIGURE 4*:* Negative trajectory showing an inversion of direction.
Absciss axis: time, **Ordinate axis:** displacement

Little is known about the kinematics of the occipital condyles. Beyer et al.[31] conducted a study on fresh cadaveric specimens measuring condyle position variation during a manual glide, finding an average magnitude of displacement from 1.8 mm to 2.6 mm and symmetrical left and right direction. Nonetheless, no studies were found evaluating the direction of condyle displacement during flexion and extension. Results from the present work are preliminary and may differ significantly different from the *in vivo* active kinematics. Moreover, the reliability of the method utilized in the present work was not assessed by other studies.

This study was performed on elder cadaveric specimens, which are not fully representative of the population that usually receives manual therapy techniques.

Furthermore, possible morphological alterations due to age might have affected the biomechanics of the joints[32–34]. The absence of innervated muscles and subject's feedback were another important difference with a real clinical setting[15]. Despite these issues, in previous studies the examiners stated that the absence of soft tissue helped to get a better grip[10,16] and there was a tendency to apply higher force on cadavers, compared to living subjects[35]. Consequently, in real treatment situation, the displacement might be smaller[9].

At present, the methodology employed in this study offers the only opportunity to perform a continuous 3D kinematic analysis of manually induced motions of the upper cervical spine.

CONCLUSIONS

This study offered a quantification of the amount of displacement induced at the atlanto-occipital joints during a passive regional flexion-extension mobilization of the cervical spine and tried to describe the trajectory of the joints' center.

The results suggest that different physiotherapists performing the same mobilization induce on average a similar amount of displacement.

The level of reproducibility of the overall motion ranged from moderate to good, while there was a greater variability for the single motion components. This may imply that, in a clinical setting, different physiotherapist could add up slightly different amounts of displacement in the three directions of space in order to reach the same position at the end of the mobilization.

After having measured the amount of displacement, the trajectories followed by the occipital articular surfaces were analyzed but no clear pattern was identified. There was a great variability even between left and right, and only the inferior displacement of the left facet and the rightward displacement of the right facet during extension were present in a significant majority of the recordings. These findings alone do not allow to draw definitive conclusions about the trajectory followed by the occipital condyles during a passive flexion-extension mobilization and they have to be compared with the results of future studies on the same topic.

KEY POINTS

- The mean flexion-extension range of motion recorded was of 18.7° (SD±6.5°), range 4.9°-34.7°.
- The mean induced displacement of the occipital condyles was of 7.0 mm (SD±4.1) on the left and 11.5 mm (SD±5.5) on the right.
- No clear pattern was identified in the trajectory of this displacement.
- Different physiotherapists are capable of reaching the same position at the end of the mobilization using different motion components.

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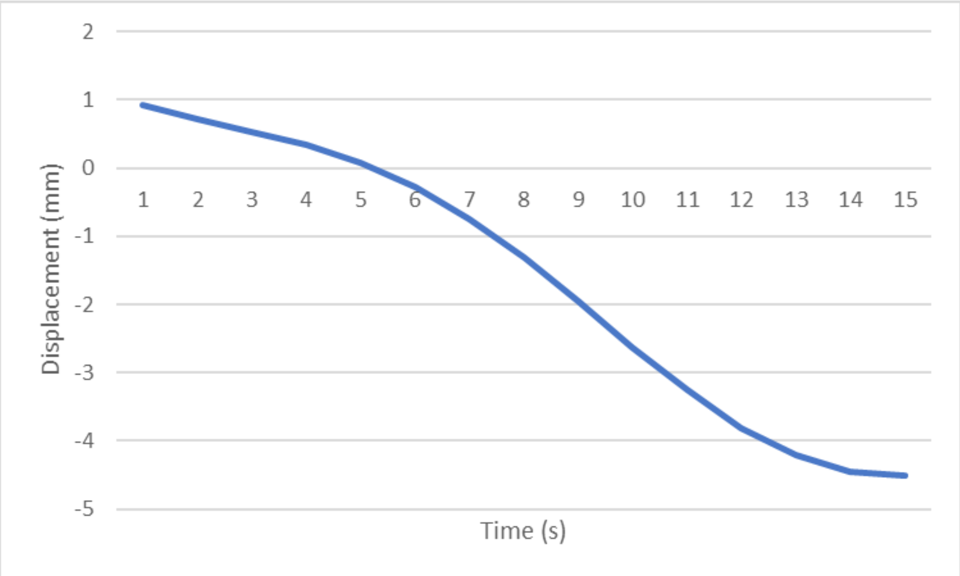
APPENDIX: TRAJECTORY ANALYSIS

The fist purpose of this analysis was to determine if the displacement followed a positive or a negative trajectory, according to the local reference frame. In the second place, the shape of the trajectory was assessed in order to identify if there were situation in which an inversion of the direction of movement was present.

Eight possible scenarios were depicted in the Mathcad© software, based on the following conditions:

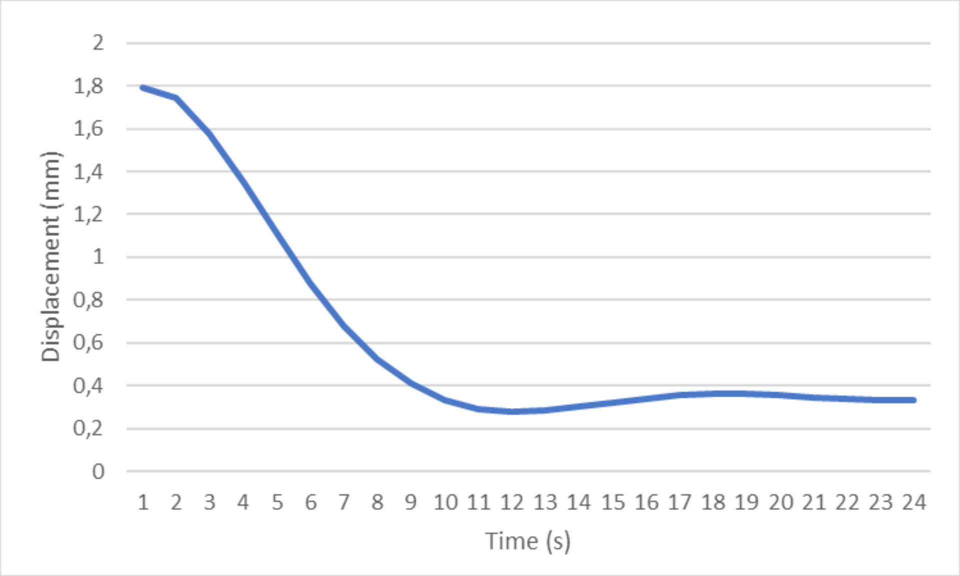
- Did the highest point of the curve come before or after the lowest point?
- Did the highest or the lowest point coincide with the start of the motion?
- Did the highest or the lowest point coincide with the end of the motion?

Type 1



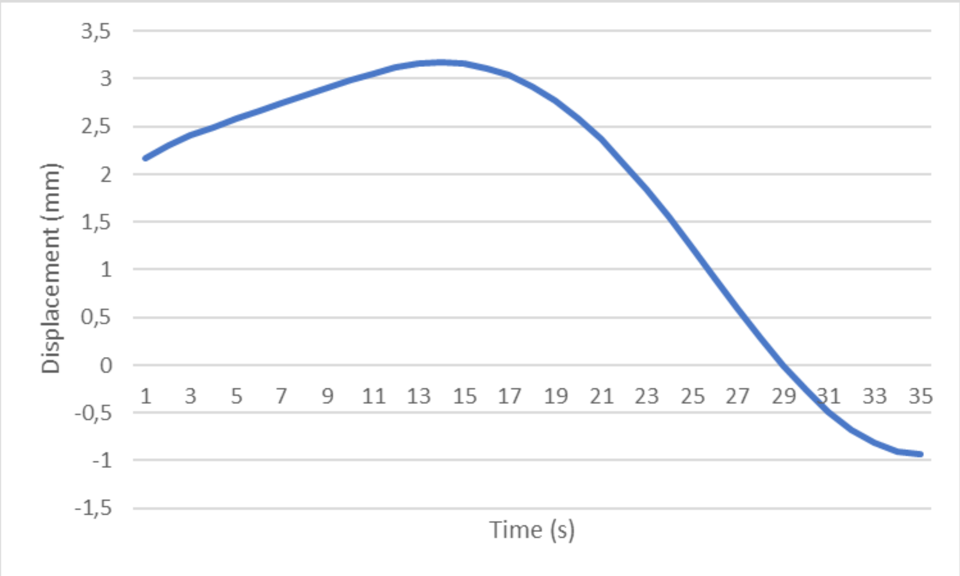
In this case, the direction is negative, the curve starts at the highest point and it ends at the lowest point.

Type 2



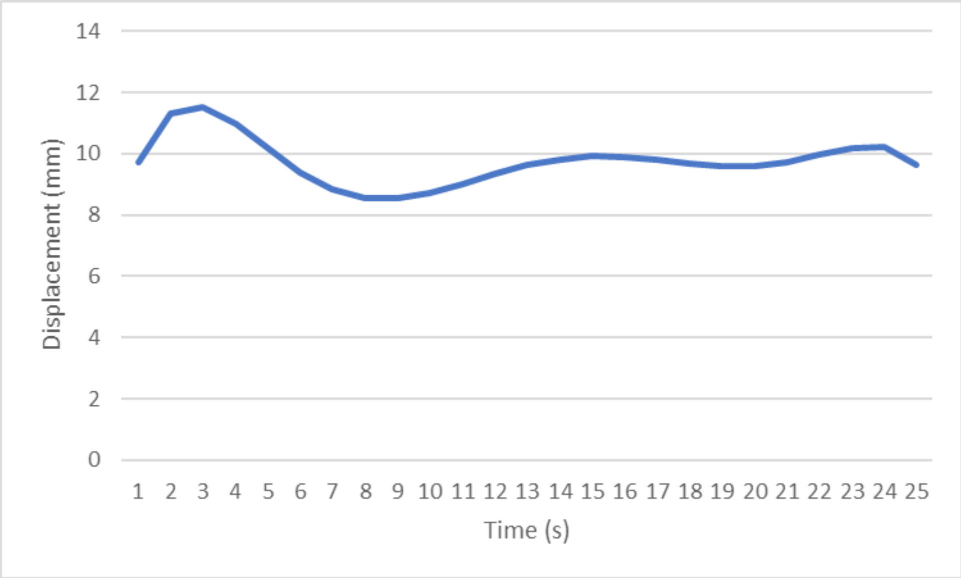
The direction is negative, the curve starts at the highest point, reaches the lowest point and then it changes direction before the end of the motion.

Type 3



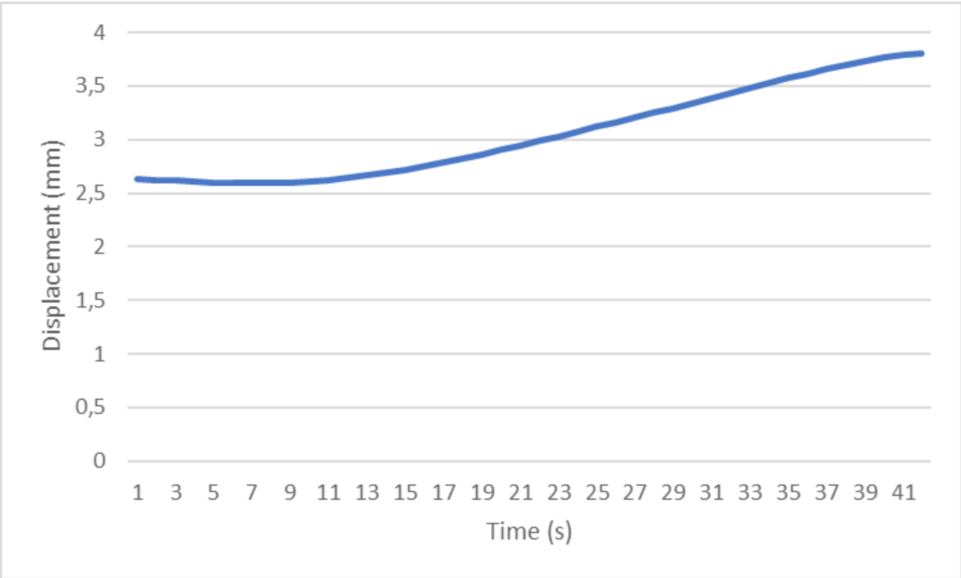
The curve starts in the positive direction, reaches the highest point and then became negative and it ends at the lowest point.

Type 4



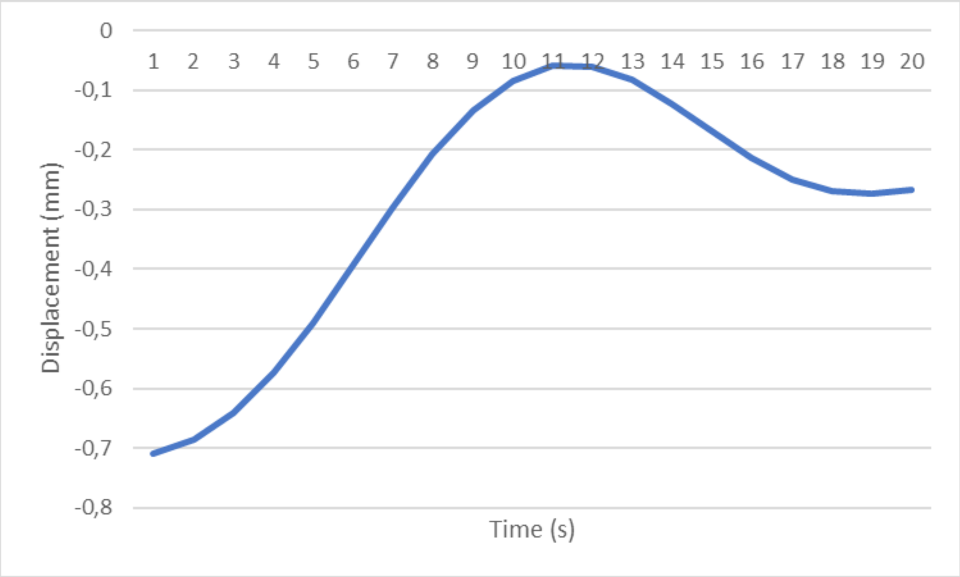
The curve starts positive, reaches the highest point, changes direction reaching the lowest point, then it changes again before the end of the motion.

Type 5



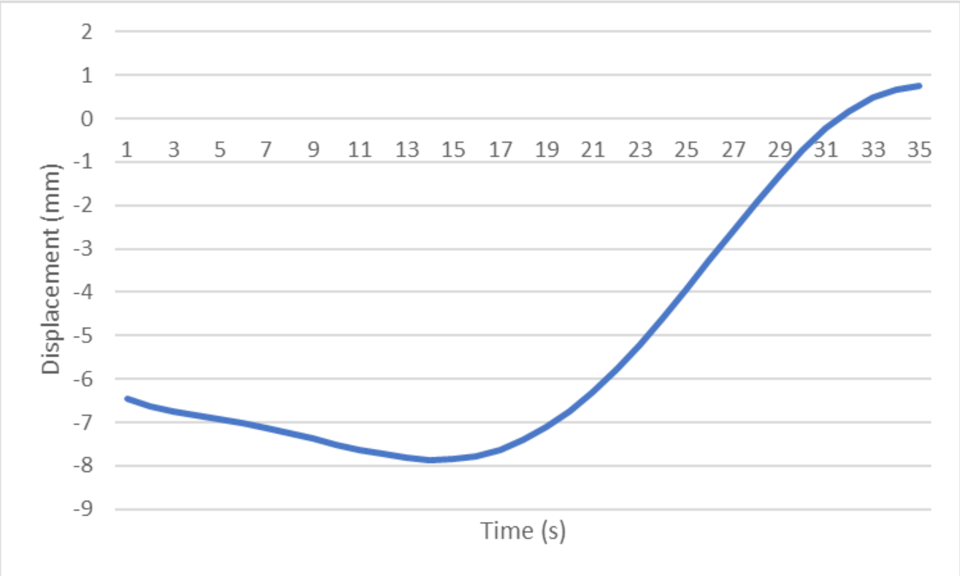
In this case, the direction is positive, the curve starts at the lowest point and it ends at the highest point.

Type 6



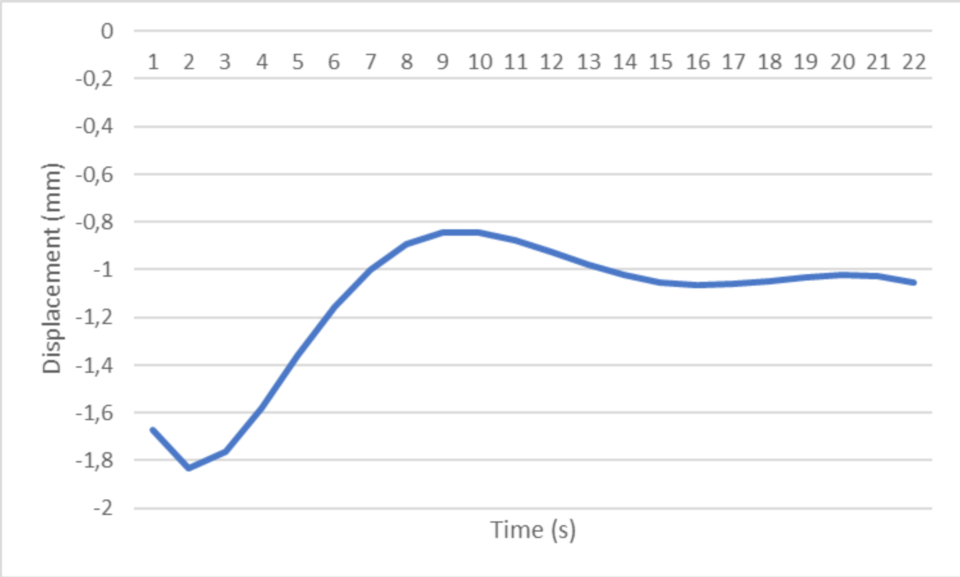
The direction is positive, the curve starts at the lowest point, reaches the highest point and then it changes direction.

Type 7



The curve starts in the negative direction, reaches the lowest point, then became positive and it ends at the highest point.

Type 8



The curve starts negative, reaches the lowest point, changes direction reaching the highest point, then it changes again.

After having observed the frequency of every type of curve for flexion and extension separately, numerical data were checked again to verify the findings.

The model revealed itself less accurate in defining the overall direction for some type 4 or type 8 trajectories, so the shape of the curve was compared with the real value of the displacement along the axis.

In addition, because in many cases there was a majority of type 2 and type 6 curves, the magnitude of the inversion of the trajectory was assessed by comparing the value of the displacement at the highest or lowest point of the curve and its start or end point.