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Atlanto-axial facet displacement during rotational high-velocity low-amplitude thrust: An in vitro 3D kinematic analysis

Luca Buzzatti [a, b], Steven Provyn [c], Peter Van Roy [c], Erik Cattrysse [c, *]

[a] Allied Health Professionals Suffolk, The Lodge, Castleton Way, Eye, Suffolk IP23 7BH, UK
[b] Department of Neuroscience, Rehabilitation, Ophthalmology, Genetics, Maternal and Child Health, University of Genova, Campus of Savona, Italy
[c] Vrije Universiteit Brussel, Belgium, Department of Experimental Anatomy, Laarbeeklaan 103, B-1090 Bruxelles, Belgium

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ABSTRACT

Background: Very little is known about the kinematics of the upper cervical spine in particular during Manual Therapy techniques. In fact no data about displacement of the atlanto-axial joint during High-Velocity Low-Amplitude (HVLA) thrust are available. Knowing the precise kinematics of these vertebrae might allow a better comprehension of such important technique and possible vital structures involvement.

Methods: A Zebris CMS20 ultrasound-based motion tracking system was adopted. Twenty fresh human cervical specimens were used in this study. Facet joint displacements of C1 relative to C2 were analysed during three consecutive HVLA thrusts into rotation. Displacement during the thrust and the maximum displacement reached with the manoeuvre were analysed.

Results: Descriptive statistics showed a mean Norm displacement during the thrust of 0.5 mm (SD ± 0.5). The maximum displacement, representing the overall facet movement from neutral to end-range position, indicated a Norm value of 6.0 mm (SD ± 3.4). Heterogeneous displacement directions were found during the thrust. Intra and inter-rater reliability reached an insufficient reproducibility level. Considering the amount of displacement induced, no statistical significant differences between the registrations were shown.

Conclusion: Displacement during the execution of HVLA thrust is unintentional, unpredictable and not reproducible. On the other hand and in accordance with other studies, the displacement induced with the present technique seems not to be able to endanger vital structure on the Spinal Cord and the Vertebral Artery. This study also adds to a better comprehension of the kinematic of the atlanto-axial segment during the performance of HVLA manipulation.

1. Introduction

Practitioners of Manual Medicine usually use High-Velocity Low-Amplitude (HVLA) thrust to manage different types of musculoskeletal disorders affecting the spine (Walser et al., 2009; Gross et al., 2010; Kuczynski et al., 2012). HVLA techniques produce different effects on the body system: mechanical effects (Triano and Schultz, 1997; Triano, 2001; Millan et al., 2012; Snodgrass et al., 2012) and neurophysiological effects (Pickar, 2002) on the axial muscles (Bicalho et al., 2010; Clark et al., 2011; Koppenhaver et al., 2011; Puentedura et al., 2011) as well as on the peripheral muscles (Herzog et al., 1999; Suter et al., 2000; Hillermann et al., 2006), and on sensitivity (Bialosky et al., 2009; Bishop et al., 2011; Sparks et al., 2013).

Because of the importance of this technique in patient management, it is essential to understand how this complex manoeuvre works from a kinematic point of view. During the last decade different authors have tried to analyse different kinematic aspects of this manoeuvre on the spinal column but the precise biomechanics are still a matter for discussion (Evans and Breen, 2006; Herzog, 2010). Although the cervical spine is still the less studied spinal segment, some information about main and coupled rotational motion components (Triano and Schultz, 1994; Klein et al., 2003; Ngan et al., 2005; Cattrysse et al., 2007a, b, 2008, 2009;

* Corresponding author. Vrije Universiteit Brussel, Fac. of Physical Education and Physiotherapy, Dep. of Experimental Anatomy, Laarbeeklaan 103, B-1090 Bruxelles, Belgium. Tel.: +32 2 477 44 50; fax: +32 2 477 44 21.
E-mail addresses: luca.buzz@gmail.com (L. Buzzatti), ecattrys@vub.ac.be (E. Cattrysse).

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Salem and Klein, 2013; Williams and Cuesta-Vargas, 2013; Dugailly et al., 2014a, b) and coupled translation motion components during HVLA thrust (Cattrysse et al., 2005; Salem and Klein, 2013; Cattrysse et al., 2014) have been described in literature.

However, nothing is known about articular facets' kinematic movement during manual mobilization or manipulation techniques. From the literature some information about normal rotational movements is available: Onan et al. (1998) reported that isolated facet joints (C3–C4 and C5–C6 segments) allowed up to 19° of flexion, 14° of extension, 28° of lateral bending, 17° of rotation and 9 mm of translation between superior and inferior surfaces. Mönckeberg et al. (2009) showed how the facet surfaces of C1 and C2 lose up to 70% of contact area (range: 42.4%–85.7%) during a 79° average neck rotation in healthy adults. Their work referred to Villas et al.'s (1999) publication where the authors reported a loss of articular contact between C1 and C2 ranging between 72% and 85% in healthy asymptomatic children. Pearson et al. (2004) reported a physiological facet joint sliding between the vertebrae pairs from C2 to C6 ranging from 1.0 mm (SD ± 0.6) to 2.2 mm (SD ± 0.8) during flexion-extension in cadaver specimens.

Because of the absence of information about facets movements during manipulation techniques, this study tries to analyse and understand upper cervical spine's facet joints displacement during the performance of HVLA thrust, in an in-vitro approach.

2. Materials and methods

2.1. Specimens

In this study a total of twenty fresh human cervical specimens were investigated, including 11 female and 9 male subjects. The mean age was 81 years (SD ± 11) ranging from 59 to 95. Each specimen included the head and the vertebrae from T2 to C1. The skin, the subcutaneous tissue and the muscles were accurately dissected leaving muscles and ligaments' insertions intact. Room temperature was controlled between 15 °C and 20 °C and humidity above 60% to prevent the dehydration of the specimens. Due to the fact that the specimens were kept frozen before examination, the biomechanical properties of tendons and ligaments have not been influenced (Panjabi et al., 1985; Wilke et al., 1998).

2.2. Instruments

A Zebris CMS20 ultrasound-based motion tracking system (Zebris Medical GmbH – Germany) was adapted to analyse the complex multidimensional kinematics of the upper cervical spine. The resolution of the instrument varied from 0.1 mm to 0.01 mm. The input data frequency of the instrument was 100 Hz. Previous studies have demonstrated to have an accuracy in reproducing angles of less than 0.1° for main motion components and 0.2° for coupled components (Cattrysse et al., 2009). Angles are calculated according to the Zebris Winbiomechanics software® (version 0.2.7, Zebris Medical GmbH, Isny, Germany) and their estimation has been commented previously (Wang et al., 2005; Cattrysse et al., 2009).

2.3. Methods

The corpus of the second thoracic vertebra was fixed in a wooden frame by fixation pins and the head simply laid on a headrest, enabling researches to take the head and move it freely (Fig. 1). The supine position of the specimen is very similar to the position of subjects on an examination table. In this way an actual clinical situation was reproduced with the best accuracy.

Fig. 1. Experimental set-up with the specimen in supine position with the Zebris system fixed.

Later on, the two transmitters and the antenna were fixed through special fixation tools. The antenna was fixed on the transverse process of the atlas while the two transmitters were fixed on the transverse process of the axis (allowing registration of atlanto-axial joint movements) and on the occiput (allowing registration of the atlanto-occipital joint movement) (Fig. 1).

Metal reference markers (Left (L), Right (R), and Frontal (F)) were inserted in each segment.

The markers were placed on the axis (left and right transverse processes and on the central part of the anterior surface of the vertebral body), on the atlas (left and right transverse processes, and the anterior tubercle) and on the head (two on the superior nuchal line at the same distance from the central one inserted on the external occipital protuberance). By digitization of these markers, the Zebris software defined three local reference frames (C0–C1–C2). By aligning them, the software was able to analyse the kinematic between C0 and C1 and between C1 and C2.

On each specimen three consecutive HVLA thrust into left rotational direction were performed. The head is supported by the contralateral hand and arm supporting the chin in a cradle hold while the neck is positioned in a combined flexion, rotation and contralateral lateral bending position. The manipulating hand is positioned against the dorsal aspect of the transvers process of the atlas. The supporting hand maintains the locking position while the working hand performs the thrust in rotational direction under slight traction (Van der EL A. et al., 1993) (Fig. 2).

The technique was not always performed unidirectional but in few cases (5 registrations up to 61) right direction was chosen in accordance with the set-up conditions. As the absolute values were taken into account, no differences in the data management were adopted.

Two investigators, with more than 10 years of experience in orthopaedic manual therapy were blinded from the data analysed by the system, and they performed the HVLA manipulations in a test-retest situation (four registrations for each specimen). The test-retest was set up under random circumstances. Before starting, both examiners were allowed to trial with one specimen to get more confidence with the experimental conditions and to reduce inter-operator biases caused by a different familiarity with the specific technique.

Consulting the International Society of Biomechanics (ISB) guideline there are no description of how to define a local reference frame for the upper cervical segments instead of the mid cervical spine (Wu et al., 2002). In spite of that, the axis labels were chosen

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Fig. 2. Direct HVLA Thrust of C1–C2. Combined motions technique.

following the ISB's guidelines as reported for the mid cervical segments (Fig. 3):

X-axis: from right to left transverse process (segmental flexion-extension axis).
Z-axis: perpendicular to the X-axis through the anterior centre of the corpus (segmental lateral bending axis).
Y-axis: perpendicular to the X and Z axes (segmental axial rotation axis).

After the performance of the technique the system was only able to calculate rotational movements of the vertebrae. To calculate the displacement of the facet joints, as the system did not have data about the 3D morphology of the atlanto-axial facet joint surfaces, a two-step approach was adopted. Using a 3D-digitizer (3D-microscribe® Immersion Corporation, USA) the metal reference markers were digitized on the full specimen and subsequently anatomical landmarks were digitized after segmentation. The center of the inferior facets of C1 and the centre of the superior facets of C2 were chosen as location of the anatomical landmark and their co-ordinates were acquired.

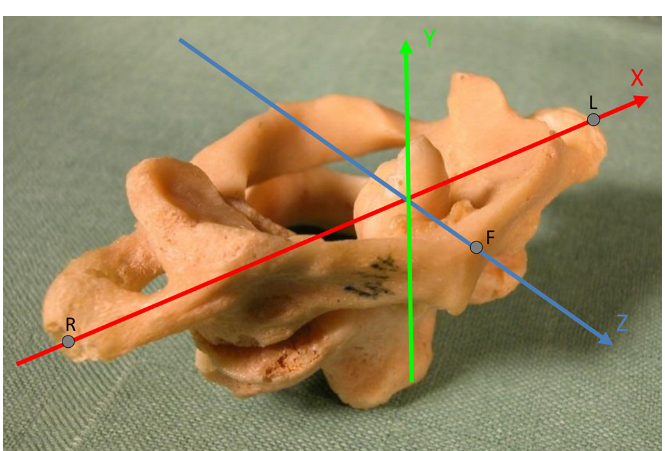

Fig. 3. Bone embedded coordinate system on C1: X-axis (segmental flexion-extension), Y-axis (segmental axial rotation), Z-axis (segmental lateral bending). Location of metal reference markers L, R, F.

The GeoGebra© (v. 5.0 Beta, International GeoGebra Institute) geometry software allowed recalculating the 3D-Digitizer's co-ordinates in the Zebris system and input them in the software. Consequently, these points were able to describe displacement movements between the facets. Therefore, the software produces a displacement output break into X-Y-Z components and expressed in millimetres. During the process of recalculation from Digitizer coordinates to Zebris coordinates, the error on the center of facets' coordinates was less than 0.01 mm.

Afterwards, first the overall displacement from neutral to end-range position and secondly the displacement during the thrust were calculated using Mathcad© professional software (v14, Parametric Technology Corporation, USA). To define when the manipulation took place, speed and acceleration were derived from angular data and the interval was tracked down. Displacement during the thrust was defined as the difference between the maximum and the minimum values of the moving point in each direction from the start of the HVLA thrust to the maximal peak reached. The maximum displacement represents the sum of the initial distance between the facets in neutral position plus the displacement in pre-manipulative position plus the displacement during the thrust. The Norm Vector ($\|v\| = \sqrt{x^2 + y^2 + z^2}$) was derived from XYZ components to express the whole 3D amount of displacement.

2.4. Statistical analysis

A One-Sample Kolmogorov–Smirnov goodness of fit test was performed to analyse the distribution of the data. In case the One-Sample Kolmogorov–Smirnov goodness of fit test showed statistical difference distribution of the data relative to a Normal distribution a Friedman two-way ANOVA by ranks test was used to highlight differences between the four registrations. The four registrations (T1, T2, R1, R2) referred to the test-retest set up: Test 1 (T1) made by Tester 1, Test 2 (T2) made by Tester 2, Re-Test 1 (R1) made by Tester 1 and Re-Test 2 (R2) made by Tester 2.

To verify the presence of outliers, Outliers Labelling Technique with a 2.2 multiplier was adopted (Tukey, 1977; Hoaglin and Iglewicz, 1987). Descriptive statistics was calculated to quantify the amount of displacement across the three planes of movement. Intra-Class Correlation Coefficient (ICC 3,1) allowed defining intra and inter-rater reliability. ICC results are interpreted according to the following classification: $< 0.40 =$ poor; $0.40–0.59 =$ moderate; $0.60–0.75 =$ good; and $>0.75 =$ excellent reliability (Fleiss et al., 2003). Significance was tested using the 5% rejection level ($p < 0.05$). All statistical calculations were made with the SPSS® software (v19, International Business Machines Corporation).

3. Results

Eleven registrations out of eighty were excluded because it was not possible to recognize the HVLA thrust as no clear acceleration moment could be detected from the angular velocity data. Eight registrations were discarded because they were detected as measurement error outliers.

Descriptive statistics (Table 1) showed a mean displacement during the thrust of 0.2 mm (SD ± 0.2) in medio-lateral direction (maximum of 1.1 mm), 0.2 mm (SD ± 0.3) in cranio-caudal direction (maximum of 1.0 mm), 0.3 mm (SD ± 0.4) in anterior-posterior direction (maximum of 1.6 mm) and a Norm of 0.5 mm (SD ± 0.5) with a maximum of 1.9 mm. The maximum displacement representing the overall facet movement from neutral to end-range indicated a medio-lateral displacement of 2.4 mm (SD ± 1.7), a caudo-cranial displacement of 2.4 mm (SD ± 2.2), an anterior-posterior displacement of 4.3 mm (SD ± 3.3) and a Norm

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Table 1
Displacement Descriptive statistics: XYZ components and the Norm resultant express in mm (Number of mobilized specimens: n = 20; total number of analysed displacements: n = 61).

		X		Y		Z		Norm	
		L	R	L	R	L	R	L	R
THRUST	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Maximum	1.0	1.1	1.0	1.0	1.5	1.6	1.8	1.9
	Mean	0.2	0.2	0.2	0.2	0.3	0.3	0.5	0.5
	SD	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
PRE M.	Minimum	0.1	0.0	0.2	0.1	0.1	0.1	1.3	0.5
	Maximum	6.1	8.1	5.8	10.0	11.0	12.9	11.1	13.4
	Mean	2.4	1.9	2.2	2.4	3.3	4.3	5.3	6.0
	SD	1.7	2.0	1.6	2.2	2.4	3.3	2.3	3.3
MAX	Minimum	0.1	0.0	0.0	0.1	0.2	0.1	1.2	0.4
	Maximum	6.2	8.5	5.8	9.8	11.0	12.9	11.1	13.4
	Mean	2.4	1.9	2.2	2.4	3.4	4.3	5.3	6.0
	SD	1.7	2.0	1.7	2.2	2.4	3.3	2.4	3.4

X = Medio-lateral displacement (Flexion-Extension axis); Y = Caudo-cranial displacement (Rotation axis); Z = Postero-anterior displacement (Lateral Bending axis); NORM = resultant of the three axes; L = Left facet; R = Right facet; SD = Standard Deviation; THRUST = displacement during the thrust; PRE M. = displacement in pre-manipulative position; MAX = maximum displacement reached with the manoeuvre from neutral position.

displacement of 6.0 mm (SD ± 3.4). Left and Right facets showed more or less the same amount of displacement during the thrust.

The displacement analysis presented a preferential rightward, upward and backward direction displacement for the right and left facet (Table 2). There were also two other direction categories: one showed opposite direction displacement relative to the preferential direction and the other one showed combined direction movements indicating a displacement in the first part of the thrust in one specific direction while throughout the second part an opposite direction may be present (Column +/−).

Intra and Inter-rater Intra-Class Correlation Coefficient (ICC 3,1) during the thrust period are reported in Table 3, while ICC values of the maximum displacement reached during the manoeuvre are reported in Table 4.

Considering the X component, only Tester 1 reached statistical significance, but with moderate reliability (0.52–0.53). No statistical significance values were reached by the Tester 2.

If Inter-rater ICC values are taken into account only seven comparisons highlighted statistically significant correlations, with reliability coefficients varying from 0.47 to 0.67.

If reproducibility is considered for the overall movement (Table 4), Tester 2 exhibited Intra-rater reliability coefficient from moderate to excellent for the X component (0.58–0.88) and for the Norm (0.46–0.80) for both facets and excellent reliability for Z component of the right facet. Only the Norm of the left facet (0.65) and Y component (0.47) of right facet of Tester 1 reached statistical significance with moderate to good reliability.

15 out of 32 inter-therapist comparisons indicated significant correlations ranging between 0.49 and 0.76.

Friedman two-way ANOVA by ranks showed statistical significance differences between the four registrations (T1, R1, T2, R2) during the thrust only for the Z component of the left facet and for the Norm of right facet. No statistical significant differences were detected considering the maximum displacement reached (Table 5).

Table 2
Displacement Direction (total number of analysed displacements: n = 61). The direction is related to the start position of the facet joints' centres.

Facet	Axis	+ % (n)	− % (n)	+/− % (n)
LEFT	X	30 (18)	42 (26)	28 (17)
	Y	52 (32)	33 (20)	15 (9)
	Z	38 (23)	41 (25)	21 (13)
RIGHT	X	36 (22)	39 (24)	25 (15)
	Y	46 (28)	36 (22)	18 (11)
	Z	23 (14)	56 (34)	21 (13)

+ = positive direction; − = negative direction; +/− = start in one direction and end in the opposite; % = percentage of displacements found in a specific direction considering the total number of analysed displacement; (n) = number of the registrations found in the specific displacement direction; X+ = leftward; Y+ = upward; Z+ = forward.

Table 3
Intra-rater (Tester 1 and Tester 2) and Inter-rater (Comparisons I, II, III, IV) Reliability of induced displacement during HVLA Thrust on C1–C2 (Expressed as Intra-class Correlation Coefficients).

	Left facet				Right facet			
	X	Y	Z	Norm	X	Y	Z	Norm
Tester 1	0.53*	−0.03	0.32	0.47	0.52*	−0.45	0.23	0.29
Tester 2	−0.08	−0.12	−0.13	−0.21	−0.06	0.09	−0.19	−0.17
I	0.47*	0.24	0.67*	0.59*	0.21	0.42	0.40	0.47*
II	−0.05	−0.30	0.36	0.07	0.10	0.24	0.37	0.27
III	−0.04	−0.15	0.21	0.15	−0.02	−0.27	−0.27	−0.31
IV	0.18	0.07	0.48*	0.48	0.20	0.09	0.64*	0.55*

X = Medio-lateral displacement (Flexion-Extension axis); Y = Caudo-cranial displacement (Rotation axis); Z = Postero-anterior displacement (Lateral Bending axis); NORM = resultant of the three axes; Comparisons: I = T1-T2, II = T1-R2, III = R1-T2, IV = R1-R2; T1 = Test by Tester 1; T2 = Test by Tester 2; R1 = Re-test by Tester 1; R2 = Re-test by Tester 2; * = Significance < 0.05.

Table 4
Intra-rater (Tester 1 and Tester 2) and Inter-rater (Comparisons I, II, III, IV) Reliability of maximum induced displacement on C1–C2. (Expressed as Intra-class Correlation Coefficients).

	Left facet				Right facet			
	X	Y	Z	Norm	X	Y	Z	Norm
Tester 1	0.31	0.09	−0.10	0.65*	0.23	0.47*	0.32	0.34
Tester 2	0.58*	−0.10	0.28	0.46*	0.88**	0.26	0.79**	0.80**
I	0.61*	0.67*	0.16	0.16	0.76**	0.54*	0.17	0.38
II	0.49*	−0.42	0.59*	0.55*	0.64*	0.36	0.25	0.42
III	0.45	−0.10	0.56*	0.27	0.40	0.06	0.57*	0.59*
IV	0.19	0.53*	0.03	0.64*	0.58*	−0.19	0.71*	0.35

X = Medio-lateral displacement (Flexion-Extension axis); Y = Caudo-cranial displacement (Rotation axis); Z = Postero-anterior displacement (Lateral Bending axis); NORM = resultant of the three axes; Comparison: I = T1-T2, II = T1-R2, III = R1-T2, IV = R1-R2; T1 = Test by Tester 1; T2 = Test by Tester 2; R1 = Re-test by Tester 1; R2 = Re-test by Tester 2; * = Significance < 0.05; ** = Significance < 0.001.

4. Discussion

Rather than study the translational and rotational motion components separately, this work tries to analyse the kinematics of

Table 5
Friedman two-way ANOVA by ranks' results. Comparison between the four registrations (T1, R1, T2, R2). XYZ components and the Norm during the thrust and the maximum displacement reached.

	X		Y		Z		Norm	
	L	R	L	R	L	R	L	R
Thrust	0.25	0.26	0.51	0.33	0.03*	0.17	0.06	0.02*
Max	0.87	0.41	0.71	0.25	0.61	0.43	0.77	0.98

X = Medio-lateral displacement (Flexion-Extension axis); Y = Caudo-cranial displacement (Rotation axis); Z = Postero-anterior displacement (Lateral Bending axis); NORM = resultant of the three axes; THRUST = displacement during the thrust; MAX = maximum displacement reached with the manoeuvre from neutral position; L = Left Facet; R = Right Facet; T1 = Test by Tester 1; T2 = Test by Tester 2; R1 = Re-test by Tester 1; R2 = Re-test by Tester 2; * = Sig. < 0.05.

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the vertebrae induced during a manual therapy technique using the amount of displacement of two points on the facet joint surfaces. Translation and rotation are defined according to the centre of a local reference frame embedded on the vertebra and they represent two distinct measures. In kinematic analysis, these values are dependent on the location of the reference system. As the reference frame is based on local anatomical repair points chosen by the researchers it does not necessarily coincide with the actual center or axis of rotation. This methodology, although commonly used in biomechanics and especially in joint kinematics, may lead to interpretative problems, especially if considering inter-segmental motions because of possible general methodological issues (Baeyens et al., 2005). As shown in Fig. 4, the components of the displacement of the center of the inferior facet of C1 relative to the superior facet of C2 can be defined as the combination of rotational components and translational components respectively around and along the three axes of the local reference frame. This combined rotational and translational displacement can be calculated for each composing coordinate (x, y, z) along each of the three axes of the local frame and in a specific direction according to its sign. However, the overall displacement presented by the norm-value is calculated as the absolute difference between two positions defined by their combined xyz-coordinates. Being an absolute displacement it is unrelated to the chosen reference system and it is not affected by possible methodological issues. As the movement is never only rotational or translational, the absolute displacement better represents the actual size of the movement between the two vertebrae. It may also offer a better and more straightforward interpretation of the kinematics of these joints as it provides a single value to interpret which can be easily compared between situations.

The Intra-Class and Inter-Class Correlation Coefficient values show that it is not possible to reproduce the displacement during the performance of the HVLA thrust (Table 3). In fact only few values reached statistical significance with low reliability coefficients. Moreover, the ICC results of the maximum displacement indicate that only one tester was partially able to acceptably reproduce the technique, although excellent reproducibility is reached only regarding the movement in the right facet. These results highlight the difficulty of manual therapy practitioners to reproduce such complex combined motion techniques. However, the experiment was performed by two examiners and despite their extensive experience, their different familiarity with the technique might have influenced the test reliability.

The ANOVA results show that only for the anterior-posterior component of the left facet and for the absolute displacement represented by the norm-value of the right facet, significant differences between test-situations were reached. This means that in general the testers were able to produce the same amount of displacement during the thrust in different specimens. From Table 2 it is possible to notice that the direction of the displacement is not consistent. Therefore, considering that the HVLA manipulations produce heterogeneous directional displacements, we may state that the induced displacement is never intentional or predictable. Although it's not possible to predict the direction of the thrust, it's known from the analysis of kinematic motion that the thrust is not able to induce an overall displacement exceeding 0.5 mm. If the single motion components X Y Z are taken into account, the separate values range from 0.2 to 0.3 mm. From a clinical point of view, values below 1 mm may be considered clinically irrelevant. Therefore, it seems plausible to state that displacements induced during the thrust of an atlanto-axial rotational HVLA technique is not able to endanger vital structures, especially at the C1–C2 level where the Vertebral Artery allows a large amount of deformation due to its double curve configuration. This conclusion is in accordance with previous studies reporting the limited impact on the elongation of the Vertebral Artery during HVLA technique (Symons et al., 2002; Wuest et al., 2010; Herzog et al., 2012a, b; Quesnele et al., 2014) and the observations of smaller angular displacements during HVLA than during slow regional axial rotation mobilization (Cattrysse et al., 2014; Cattrysse et al., 2015).

The induced maximum displacement varies from 1.9 mm (SD ± 2.0) for the X component to 6.0 mm (SD ± 3.4) for the Norm. These data are well acceptable, even if the maximum value of the Norm is taken into account (13.4 mm), as the displacement is a combination of rotation and translation. This relatively high value seems to be acceptable considering the large capsular laxity of C1–C2. It is known from literature that, when performed in cadavers, HVLA thrust tends to be more "aggressive" in terms of all biomechanical indices used to describe spinal manipulation (Symons et al., 2012), and if we consider that the preliminary removal of soft tissues, the lack of muscular tonus might have allowed wider movements. As such the results reported might even be slightly overestimating the actual in vivo situation. Cattrysse et al. (2015) and Dugailly et al. (2014b) pointed out that the movement during the HVLA thrust might be even smaller than in vivo subjects.

Tucker and Taylor (1998) reported that at the extreme of physiological axial rotation (47°) the cross-sectional area of the spinal canal in neutral position is reduced to 61%, with a residual area subtracting the cord of 34%. Using the radiographies presented in that study, we estimated the 2D displacement of the center of the facets from neutral position to the maximum reached after 47° axial rotation. An approximate 15 mm 2D displacement was calculated from this approach. Duan et al. (2007) reported an absolute facet displacement approximating 7.6 mm during active head rotation in supine position of normal in vivo subjects. These values are bigger than the 6 mm Norm displacement found in our in vitro study. The displacement induced with the manoeuvre is close to the displacement reached by active rotational movement, suggesting equal strain on vital structures than daily active rotation of the head.

The characteristics of the sample might have influenced the study's results. Possible morphological alterations due to age might have affected the biomechanics of the joints. It has been proved that the specific anatomical features of the cervical zygapophysial joints and the age of the subjects might affect the kinematics of these joints (Nowitzke et al., 1994; Trott et al., 1996; Seacrist et al., 2012). Moreover, the age of specimens was not representative of the population that usually receives this kind of manual techniques. However, there is evidence from literature that suggests that rotation of the C1–C2 segment does not decrease with age, but

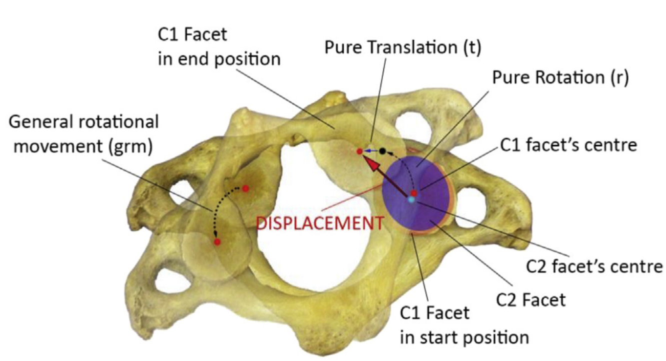

Fig. 4. C1–C2 joint. 2D general rotational movement on the horizontal plane (grm = r + t). Inferior view. The displacement is a combination of pure translation (t) and pure rotation (r). C2 movements are not considered to avoid confusion.

rather increases slightly to compensate for the overall decreased motion in the lower segments (Dvorak et al., 1992; Castro et al., 2000).

Further in vitro and if possible in vivo research in this field may be worthwhile for a better comprehension of complex intervertebral motion of the atlanto-axial joint during HVLA techniques and to confirm the safety of this manoeuvre.

5. Conclusion

The results of the present study suggest that displacement during the execution of HVLA thrust is unintentional, unpredictable and not reproducible, although the general amount of induced displacement is reproducible. In accordance with other studies, the displacement induced with the present technique seems not to be able to endanger vital structure on the Spinal Cord and the Vertebral Artery more than active rotation of the head. This study also provides a better comprehension of the kinematics of the atlanto-axial segment during the performance of HVLA thrust.

Conflict of interest

The authors have no conflict of interests to declare.

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