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Coupled translation motions of the upper cervical spine during rotational high velocity low amplitude thrust: a 3D in vitro kinematic analysis of atlanto-axial joint .

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VRIJE UNIVERSITEIT BRUSSEL • SCIENTIA VINCERE TENEBRAS •

"Sensate experiences and necessary demonstrations"

G. Galilei (1564-1642)

Acknowledgement

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Luca Buzzatti

ABSTRACT

Background:

The use of HVLA techniques for neck disorders is common in Manual Therapy. However, in the last years only few authors have done some researches in this field and they have tried to analyze different kinematic aspects of this manoeuvre. Although there are some publications about main axial movements, very little is known about coupled motions, in particular about translations. This study tries to analyze and understand translational couple motions during HVLA thrust of the upper cervical spine in vitro specimens.

Material and Methods:

A Zebris CMS20 ultrasound-based motion tracking system has been adopted to explore the complex multidimensional kinematic of the upper cervical spine. Translation data from C1-C2 segments were analyzed. Twenty fresh human cervical specimens were used in this study. Translational motions along the three planes were analyzed during three consecutive HVLA thrust into rotation performed in a test-retest set up by two researchers. Descriptive statistics, thrust direction, ICC and Friedman two-way ANOVA were calculated.

Results:

The results indicates a prevalent medio-lateral left translation of 0.7 mm (SD ± 0.8), a caudo-cranial translation of 0.9 mm (SD ± 1.3) and a prevalent posterior-to-anterior translation of 0.6 mm (SD ± 0.8). They respectively range from 0 to 4.5 mm, from 0 to 7 mm and from 0 to 4 mm. Intra-rater ICC varies from 0 to 0.47. Inter-rater ICC varies from 0 to 69. However, except for few results no statistical significance is reached. The Friedman two-way ANOVA by ranks shows no differences between the four measurements.

Conclusion:

The results indicate that coupled translations during rotational HVLA thrust at the atlanto-axial level are unintentional, unpredictable and not reproducible. Because of a methodological issue, the results are overestimated and it is not possible to calculate this overestimation. Thus, any reliable conclusion over the safety of this manoeuvre should be interpreted with care. Further research with different methodological approaches should be done to better quantify and understand translational coupled motions during HVLA thrust.

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1. ITRODUCTION

Practitioners of Manual Medicine usually use High-Velocity Low-Amplitude (HVLA) thrust to manage different types of musculoskeletal disorders affecting the spine (Kuczynski, 2012; Walser 2009; Gross 2010). The decision of Manual practitioners to refer patients for Spinal Manipulative Therapy (SMT) should be based upon costs, preferences of the patients and providers, and relative safety of SMT compared to other treatment options (Rubinstein, 2012).

HVLA techniques produce different effects on the body system: mechanical effects (Triano and Shultz 1997; Triano 2001; Millan et al. 2012; Snodgrass SJ 2012) and neurophysiological effects (Pickar, 2002) on the axial muscles (Clark, 2011; Bicalho, 2010; Koppenhaver, 2011; Puentedura, 2011), on the peripheral muscles (Suter 2000; Hillermann B 2006; Herzog 1999) and on sensitivity (Bialosky, 2009; Bishop, 2011; Sparks, 2013).

Although the current action mechanism is questionable (Evans,2002 and Khalsa,2006 in Rubinstein, 2012) and little is known about the precise biomechanics (Herzog, 2010; Evans, 2006), the study of kinematics is still a cornerstone in the understanding of Spinal Manipulation. Concerning manipulation, cervical spine is one of the region less investigated. Several studies dealt with this lack of information, analysing different aspects of this technique, however, results often disagree. The differences among the studies may depend on different techniques (Hing 2003) and methods used to analyze the movement and the level of the manipulators' expertise (Triano, 2011).

Salem and Klein's (2013) 3D kinematics analysis (CT) of the cervical spine shows a pre-manipulative mean axial rotation of 28.8° ± 10.4° which is in close agreement with the results (30°±9°) of Klein et al. (2003) but lower than the 40° of Triano and Shultz (1994). Lateral flexion of 46°± 8° reported by Klein et al. (2003) and 26°direct break technique (except for 12° rotatory technique) by Triano and Schultz (1994) was found to be higher than the measurement (16.2 °± 11°) of Salem and Klein (2013). The range of motion found in the sagittal plane (7.7° ± 5.3°) is higher than that of Klein et al. (2003) and lower than those of Triano and Schultz (1994). The latter, found a mean angle displacement of 13° compared with the 11° of Ngan et al (2005).

Williams et al. (2013)'s results suggest that upslope pre-manipulative position was achieved with just 8.5°± 4.7° of rotation and 27.25° ± 3.8° of lateral flexion that highly differ from Ngan et al. (2005)'s mean pre-manipulation position of 53.6° ± 7.0 of rotation and 5.6 ± 11.9° of lateral flexion.

Symons et al. (2012) reported a peak force delivered of 190.3 N over 178 ms during cervical spine manipulation which is quite different from 107 N over 81 ms reported in a review by Herzog (2010) and the data of different studies reported in another review by Downie et al. (2010).

Also Reproducibility of this techniques has been subject matter for the research. Cattrysse et al. (2013) showed fair to moderate levels of intra-examiner correlation of main axial rotation and coupled lateral bending (0.35;0.64) and a moderate inter-examiner correlation (0.52; 0.54) during rotational HVT of C1-C2 segment in vitro. In the same way Ngan et al. (2005)'s results indicate distinct differences in the pre-manipulation positions used by different therapists (ICC 0.48 rotation, 0.32 lateral flexion) except for Intra-rater correlation (ICC axial rotation 0.74, lateral flexion >0.75) in a single session and between session (ICC axial rotation 0.78, lateral flexion 0.84).

3D arthrokinematic analysis of coupled motions of Upper Cervical Spine has been an argument more and more studied concerning mobilisation techniques both in vitro (Cattrysse et al. 2007a,b; Cattrysse, 2008; Cattrysse 2009) and in-vivo subjects in the last years. However, very little is known about HVLA techniques. Salem and Klein (2013) reported a mean pre-manipulative downward translation of 1.3 mm (SD±1.5) at C1-C2 level and a multidirectional mean translation at C0-C1 level (1.5 ± 1.3 mm in lateral direction, 0.7 ± 1 mm in posterior direction and 0.5 ± 0.4 mm in inferior direction). However, the only data available, at the best of authors knowledge, show that during HVT traction on the C0-C1 level the thrust results in a 3-dimensional translation with main lateral direction coupled with a smaller axial and sagittal displacement. The rotational HVT on the level C1-C2 results in an additional axial rotation component of approximately 2°, with almost no rotational components in flexion-extension or lateral bending directions. This axial rotation component is however again accompanied by translational displacements in all three directions (Cattrysse 2005).

The present study focuses on the analysis of translational coupled motion components between C1 and C2 during rotational HVLA thrust.

2. METHODS AND MATERIALS

2.1. Specimens

In this study a total of twenty fresh human cervical specimens have been 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 dissected with the accuracy of living 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., 1989).

2.2 Instruments

A Zebris CMS20 ultrasound-based motion tracking system (Zebris Medical GmbH – Germany) has been adopted to analyse the complex multidimensional kinematics of the upper cervical spine. The measuring method is based on the travel time measurement of ultrasonic pulses transmitted by three miniature transmitters (markers) to the three microphones built into the measuring sensor (antenna). The fully digitized conditioning of the sonic signals received, provides high measuring accuracy. The resolution of the instrument varies from 1/10 mm to 1/100 mm. The input data frequency of the instrument was 100 Hz/s. Previous studies has been demonstrated to have an accuracy in reproducing angles of less than 0.1° for main motion components and 0.2° for coupled components (Cattrysse, 2009). Although the methodology used for angles calculation according to Zebris Winbiomechanics software® (version 0.2.7, Zebris Medical GmbH, Isny, Germany) is unclear, some authors have tried to solve this issue (Cattrysse, 2009; Wang, 2005).

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 move freely the superior part (Fig. 1). The supine position of the specimen is very similar to the position of subjects on an examination table. In this way we reproduce with the best accuracy an actual clinical situation.

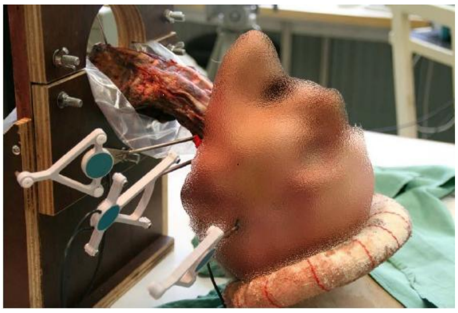

Fig. 1. Experimental set-up with the specimen in supine position and fixation of the ultrasound system.

Later on, the two transmitters and the antenna were fixed through specially fixation tools. The antenna was fixed on the transverse process of the atlas while the two transmitters 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). Metal reference markers (Left(L), Right(R), Frontal(F)) were inserted in each segment to allow Zebris software to define the local reference frame by digitization of these markers (Fig. 2a and 2b). 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). The markers allocated in each segment allowed to define three different local frames (C0 - C1 - C2). By aligning it was possible to calculate the movements between CO and C1 and between C1 and C2.

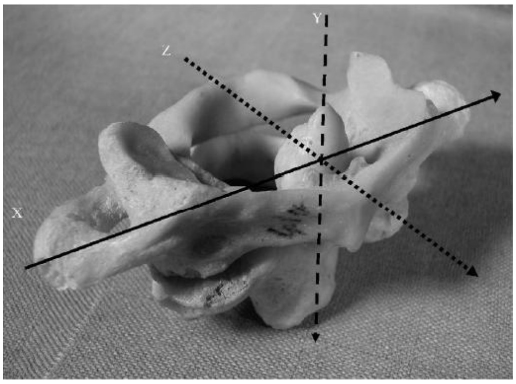

Fig.2a C1 Local reference frame

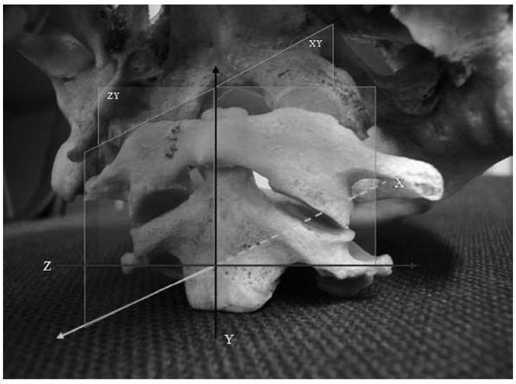

Fig. 2b C2 Local reference frame

The accurate location of the fixation tools and the preliminary dissection ensured the possibility to move the specimens' cervical spine in the required directions: lateral bending, axial rotation, flexion-extension and combined movements.

On each specimen three consecutive HVLA thrust into rotational direction were performed. (Fig.3) The technique is based on a combined movement technique that allows to reach the pre-thrust position using less than maximal axial rotation. The therapist’s right index finger is placed on the arch of the atlas and the left forearm supports the occiput. The occiput is side bended to the right, which effects left rotation at C1–C2. This is followed by further rotation of the C1–C2 joint until the end range for that segment is determined. The thrust is given via the right hand in an upslope direction towards the lower aspect of the left orbit (Hing, 2003).

Fig. 3 Direct HVT of C1–2. Upslope or rotation technique to the left (the arrow indicates direction of thrust). Hing, 2003

The technique was not always performed unidirectional, in few cases right side was changed depending on the set-up conditions. Two investigators, blinded from the analysis data of the system, with more than 10 years of experience in orthopaedic manual therapy, performed the HVLA manipulations in a test-retest situation. 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 the technique 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 following the ISB's guidelines as reported:

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

Zebris Winbiomechanics software® allows to define an extra point through the three reference markers (R,L,F): the C point. The intersection of the three axis of rotation (X, Y, Z), passing through the three reference markers, produces a C point that is to be considered the center of the local bone embedded reference frame and It is independent from any rotational movement performed during the test. Consequently, this point was able to describe the translational movements along the three accesses of the reference frame. Therefore, the software produce a translational output break into X-Y-Z components and expressed in millimetres. Afterwards, the amount of translations was analyzed and calculated with Mathcad® professional software (version 14). Translation was defined as the difference between the maximum and the minimum values of the C point in each direction assumed from the start of the HVLA thrust to the maximal peak reached. To define when the manipulation took place, speed and acceleration were derived from angular data and the interval was tracked down (Fig. 4).

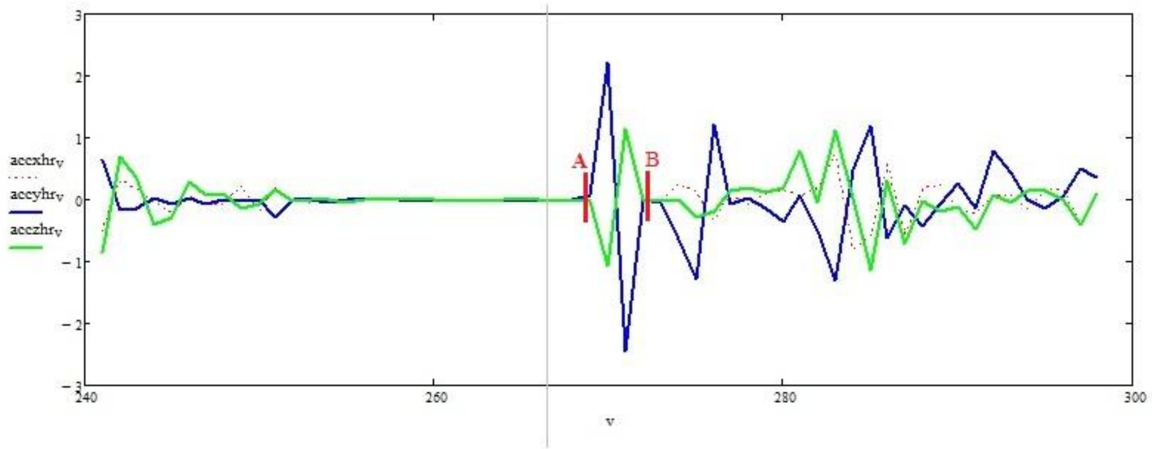

Fig.4 Acceleration graphic. A: Start of the thrust B: end of the thrust

2.4 Statistical analysis

One-Sample Kolmogorov-Smirnov goodness of fit Test was performed to analyze the distribution of the data. In case data do not show a Normal distribution, non-parametric tests would have to be used. Descriptive statistics was calculated to quantify the amount of translation across the three planes of movement. To express the whole 3D amount of translation the Norm Vector ($\|v\| = \sqrt{x^2 + y^2 + z^2}$) was derived from XYZ components. Intra-Class Correlation Coefficient (ICC) permitted the authors to define the intra and inter-rater reliability. ICC results are interpreted according to the following classification: <0 is 'poor', 0–0.20 'slight', 0.21–0.40 'fair', 0.41–0.60 'moderate', 0.61–0.80 'substantial' and 0.81–1.00 'almost perfect' (Landis and Koch, 1977). Significance was tested using the 5% rejection level ($p < 0.05$).

All statistical calculations were made with the SPSS® software (19th version).

3. RESULTS

Eight tests out of eighty have been excluded because no HVLA thrusts were recognised. This decision was based on the study of the acceleration and rotational values.

The One-Sample Kolmogorov-Smirnov goodness of fit Test shows statistical difference distribution of the data respect to a Normal distribution. Therefore, Friedman two-way ANOVA by ranks was used to calculate differences between the four registrations. The mean from the study of the descriptive statistic during the HVLA thrust period and the direction of the thrust are reported in Table 1 and 2. They indicate a prevalent medio-lateral left translation of 0.7 mm (SD ± 0.8), a caudo-cranial translation of 0.8 mm (SD ± 1.1) and a prevalent posterior-to-anterior translation of 0.6 mm (SD ± 0.8). They respectively range from 0 to 4.5 mm in the medio-lateral coupled translations, from 0 to 5,0 mm in the caudo-cranial translation and from 0 to 3.9 mm in the posterior-to-anterior translation. The Norm related to the three translational vectors, which represents the whole 3D motion, shows a mean of 1.3 mm (SD ± 1.5), ranging from 0 to 5.7 mm.

Table 1. Descriptive statistics of translations along the XYZ axes and the Norm resultant (number of mobilized specimens: n= 20)

		T1	R1	T2	R2	TOT
X	Minimum	0	0,1	0	0	0
	Maximum	4,5	2,2	2,5	2,0	4,5
	Mean	0,8	0,7	0,6	0,6	0,7
	SD	1,2	0,7	0,7	0,7	0,8
Y	Minimum	0	0,1	0	0	0
	Maximum	2,6	5,0	4,5	3,7	5,0
	Mean	0,8	0,9	0,9	0,8	0,8
	SD	0,9	1,1	1,5	0,9	1,1
Z	Minimum	0	0	0	0	0
	Maximum	3,9	2,2	1,7	1,7	3,9
	Mean	1	0,6	0,3	0,5	0,6
	SD	1,2	0,6	0,4	0,5	0,8
NORM	Minimum	0,1	0,1	0,1	0	0
	Maximum	5,6	5,7	5,2	4,2	5,7
	Mean	1,5	1,3	1,3	1,3	1,3
	SD	1,8	1,4	1,5	1,1	1,5

X= Flexion- Extension; Y= Rotation; Z= Lateral Bending; Norm= resultant of the three axes T: Test; R: Retest; 1:Tester 1; 2: Tester 2; TOT= total number of analyzed translations: n=72; SD= Standard Deviation

Table2. Translations' Direction (total number of analyzed translations: n= 72)

Axis	+	%	-	%	+/-	%
X	50	69	12	17	10	14
Y	40	56	14	19	18	25
Z	44	61	20	28	8	11

X+ = left translation Y+=up translation Z+= anterior translation +/- = start in one direction and end in the opposite

The results in table 2 indicate three type of translation directions with one preferential direction: 69% of medio-lateral translations are leftwards, 56% of caudo-cranial translations are upwards and 61% of postero-anterior translations are forward (Column +). The other results show both opposite translations (Column -) and, in some cases, translations in the first part of the thrust are in one specific direction while throughout the second part an opposite direction may be present (Column +/-).
The results of intra-rater reliability and inter-rater reliability are shown in Tables 3 and 4. The intra-rater ICC of single components (XYZ) vary from 0 to 0.47. Except for one measure (X component in rater 1),all results show poor to moderate reproducibility, without statistical significance. Considering the Norm values, only for one rater (i.c. rater 2) statistical significance is reached but even in this case the ICC's value shows moderate reliability (0.45).
The results for Inter-rater (Table 4) ICC vary from 0 to 0.69 but only for four cases statistical significance is reached.

Table 3. Intra-rater Reliability for translational motion components during rotation HVT on C1-C2 (expressed as Intra-class correlation coefficients)

	T1			T2		
	ICC	CI 95%	Sig.	ICC	CI 95%	Sig.
X	0.47*	-0.01 - 0.78	0.03	0,31	-0.42 - 0.8	0.10
Y	-0.06	-0.53 - 0.43	0.06	0.32	-0.37 - 0.81	0.09
Z	0.37	-0.14 - 0.72	0.07	0.32	-0.16 - 0.68	0.09
NORM	0.03	-0.23 - 0.67	0.14	0.45*	-0.14 - 0.86	0.03

X= Flexion- Extension; Y= Rotation; Z= Lateral Bending; Norm= resultant of the three axes; T1: Tester 1; T2: Tester 2; CI= Confidence Interval; Sig.= Significance; *= Sig. < 0.05;

Table 4. Inter-rater Reliability for translational motion components during rotation HVT on C1-C2 (expressed as Intra-class correlation coefficients)

		I	II	III	IV
X	ICC	0	- 0.08	0.26	0.69*
	CI 95%	-0.5 - 0.5	-0.54 - 0.42	-0.24 - 0.65	0.33 - 0.88
	Sig.	0.05	0,04	0.15	0.001
Y	ICC	0.13	0.17	-0.2	-0.02
	CI 95%	-0.4- 0.6	-0.34- 0.6	-0.61 - 0.3	-0.48 - 0.45
	Sig.	0.32	0.25	0,06	0.53
Z	ICC	0.59*	0.01	0.24	0.24
	CI 95%	0.13 -0.84	-0.4 - 0.56	-0.26 - 0.64	-0.26 - 0.64
	Sig.	0.01	0.34	0.17	0.17
NORM	ICC	0,47*	0.19	0.22	0.64*
	CI 95%	-0.31 - 0.78	-0.32 - 0.62	-0.27 - 0.63	0.24 - 0.85
	Sig.	0.03	0.23	0.19	0.002

X= Flexion- Extension; Y= Rotation; Z= Lateral Bending; Norm= resultant of the three axes; CI= Confidence Interval; Sig.= Significance; *= Sig. < 0.05; Comparison: I = T1-T2, II = T1-R2, III = R2-T1, IV = R1-R2

The Friedman two-way ANOVA by ranks (Table 5) shows no significance differences between the four measurements. Therefore no other non-parametric tests were performed.

Table 5. Friedman two-way ANOVA by ranks. Comparison between the four tests (T1-R1-T2-R2)

	SIG.
X	0.65
Y	0.63
Z	0.30
NORM	0.93

X= Flexion- Extension; Y= Rotation; Z= Lateral Bending; Norm= resultant of the three axes; Sig.= Significance
T: Test; R: Retest; 1:Tester 1; 2: Tester

4. DISCUSSION

Coupled movements of the upper cervical spine induced during manual techniques, have been more and more investigated and reported in literature in the last years but not all kind of techniques neither all coupled motions have been examined. In fact only few authors have done some researches on this field (Cattrysse et al. 2007a,b; Cattrysse, 2008; Cattrysse 2009; Cattrysse, 2005; Salem and Klein,2013). The present study tries to analyze and understand coupled translational movements during High Velocity Low Amplitude Manipulations in vitro specimens.

The descriptive statistics indicates similar amount of translations in medio-lateral direction (X axis), caudo-cranial direction (Y axis) and postero-anterior direction (Z axis). With regard to the whole 3D movement, the results are roughly the same for each test. The range vary from 0 to 5 mm. Values below 1 mm should be accounted as not clinically relevant. Although there is a preferential translational direction for each axes (maximum of 69% along the X axis), the remaining results show opposite or combine translations. So the direction of the translations is not consistent. Considering that the HVLA manipulations produce heterogeneous directional translations the statistical analysis did not show that these differences were statistically significant. Therefore we may state that the amount of induced translation is usually similar but never intentional or predictable. Taking into account the mean of the calculated translations (vary from 0.6 to 1.3 mm), the values seem to be well acceptable. However, if the maximum values of the translation ranges are taken in account (range from 3.9 to 5.7 mm), it does not appear to be possible to have such large amount of inter-vertebral movements. Ishii et al. (2006) reported a 7.7 mm (SD ± 1.9) coupled lateral translation at C1-C2 level during active lateral bending of the neck. However, they considered the movement from the neutral position to the maximum range of motion. In the same way Salem and Klein (2013) reported a 1.3 mm (SD ± 1.5) downward translation at C1-C2 level to reach the pre-manipulative position. The present study takes in account only the short fraction of time necessary to perform the thrust and not the whole movement from the neutral position. The large translational motion components reflect merely general methodological issues related to the representation of motion analysis. Above all, they lead to interpretative problems, especially if considering inter-segmental motions. This can best be demonstrated starting from a 2D-approach. The start position (Fig. 5a) shows the reference frame in S and the center of actual rotation that took place in C. The tester induces a pure rotation α that moves the reference frame from S to E (Fig 5b). As it is not possible to know exactly where the location of C is, to calculate the orientation change of the reference frame it is necessary to superimpose the frame of E with the reference frame of S so that the two reference centres coincide (Fig. 5c). At this point, we are able to calculate the angle between the two frames that corresponds to the angle of rotation α. In order to calculate the change in position, we apply a translation *t* from the start position up to the end (Fig. 5d). As a result, we obtain exactly the same position and orientation of the frame instead of rotating the frame around the center C (compare Fig. 5b and 5d).

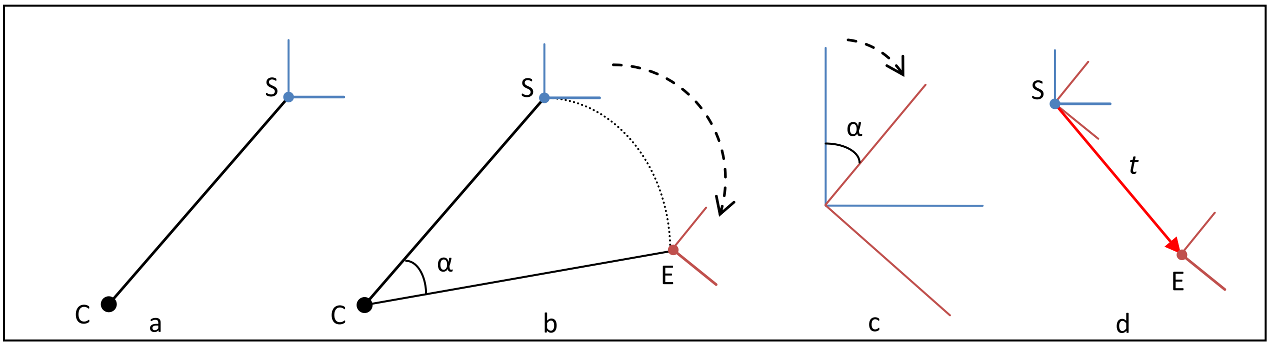

Fig.5 Methodology used to calculated the translations. a: start position. b: rotation of the reference frame around the center of rotation. c: superimposition of the two reference frames and calculation of the angle α. d: translation of the reference frame.

Despite the occurrence of a pure rotation, the final calculation with this approach shows a combination of rotation and translation. The amount of calculated translation changes according to the distance from the center of the frame to the real center of rotation. The bigger the distance from the rotation center is, the bigger becomes the calculated translation. As explained in the material and methods' section a central point (0,0,0) from a bone embedded reference frame, was defined in the center of the vertebra to calculate the amount of angular and translational inter-vertebral motion. This point does not coincide with the real center of rotation, thus, the final translation result is calculated by summing up the real translation of the vertebra and the translation applied to the frame as shown in figure 5. As one does not know how far the real center of rotation is, it is impossible estimate how much extra translation is added. This methodological issue should partially explain the large amount of translation found during HVLA thrust.

In accordance with the present results, translational coupled motions during HVLA thrust seem not to be reliable for the majority of the calculations.

Friedman tow-way ANOVA by ranks shows no differences between the four groups of data indicating that the general amounts of translation producing during the thrust do not statistically differ from one tester to the other and from test to retest.

Literature's data on dimensions of the Foramen Transversarium show a mean diameter around 6.1 mm for C1 and 5.1 mm for C2 (Bumin, 2013; Gupta, 2013; Shilpa, 2012; Taitz, 1978). For Arteria Vertebralis' diameter was found a mean value around 3.5 mm (Mitchell, 2008). The data of the present study show a maximum translation along the horizontal plane of 4.5 mm. If the calculated translations of the center of the reference frame would be representative for real inter-vertebral translational movements this could endanger the vertebral artery because of occlusion; even though the AV allows a large amount of deformation at the level of C1-C2 due to the double curve configuration. Therefore it does not seem indicate to compare the present results with data from other studies reported in literature that underline the safety of the described HVLA technique. (Quesnele, 2014; Herzog, 2012a,b; Symons, 2002). As previously stated, the calculated translations of the center in the present study are probably overestimating the real translation. However, the real amount of displacement between the two vertebrae at the level of the Foramen Transversarium cannot be estimated through this approach. Other analysis techniques, for example Finite Helical Axis calculation, or contact areal analysis , might allow to estimate translation along the Helical Axis as a better approximation of inter-vertebral translations.

Limitations of the study

The characteristics of the sample might have influenced the study. Possible morphological alterations due to age might have affected the biomechanics of the joints. It has been proved that the specific anatomy of the cervical zygapophysial joints and the age of the subjects might influence the kinematics of these joints (Nowitzke et al., 1994; Seacrist,2012; Trott, 1996). Moreover the specimens were not representative of the population that usually receive this kind of manual techniques.

This is an in vitro study, thus, even if fresh cadavers were used and the biomechanical property of tendons and ligaments had not been influenced, the dissection of the neck may have altered cervical motion, allowing wider movements. On the one hand the absence of soft tissues might have advantaged the researchers in offering a better grip, but on the other it might have changed part of the execution of the manipulation as for the intensity of the thrust (Symons et al, 2012).

The experiment was performed by only two examiners and despite their extensive experience and the opportunity to trial with a specimen before the experiment, their different familiarity with the technique might have influenced the test reliability. This may explain the inconsistency in inter- and intra-rater reliability results.

As previously reported the methodology used to analyze 3D kinematics plays a major role. The impossibility to define with high accuracy the real center of rotation of the segment can output larger translational coupled movements. A first attempt to overcome this problem may be by using the Finite Helical Axis approach, which allows to define a single axis to describe an entire rotational movement without necessity to define a local reference frame to interpret rotational and translational motion components. This property may be very useful to calculate translations, as it has already been done for rotational movements (Cattrysse 2007a,b; Salem and Klein, 2013), for pre-manipulative position (Salem and Klein, 2013) and for pathological condition (Ellingson, 2013). However, also this approach may create difficulties in describing translational components, as the true motion will be a combination of translations along the FHA and the translations of the FHA.

Another way may be estimating changes in position of the center of the Foramen Transversarium as indicator of translations and possible vertebral artery involvement.

As already reported for the knee (Leszko, 2011; Iseki, 1976) and the glenohumeral joint (Baeyens, 2000; Baeyens, 2001), also the contact area approach might be useful to calculate positional displacements of the inferior articular facets of C1 with respect to superior facets of C2 and provides a better comprehension of inter-vertebral spinal motion.

Further in vitro and if possible in vivo research in this field may be worthwhile for a better comprehension of complex inter-vertebral motion, including translational motion components, during HVLA manoeuvres.

5. Conclusion

The results of the present study indicate that coupled translations during rotational HVLA thrust at the atlanto-axial level are unintentional, unpredictable and not reproducible. Because of methodological issues, the results are overestimated and it is not possible to calculate this overestimation. Thus, any reliable conclusion over the safety of this manoeuvre should be interpreted with care. Further research with different methodological approaches should be done to better quantify and understand translational coupled motions during HVLA thrust.

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