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Reliability analysis of manual fixation during 3-dimensional mobilization techniques of upper cervical spine.

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Abstract

Background: There are very few studies that investigate the intra- and inter- operators reliability of the 3D mobilizations, performed with manual fixation and applied to the upper cervical spine.

Objective: The present study was performed to evaluate the intra- and inter- examiners reliability and the reproducibility of the manual fixation.

Methods: Twenty fresh human spinal specimens were studied, whose 9 male and 11 females, in a test-retest situation and an adapted Zebris CMS20 ultrasound-based motion tracking system (Zebris Medical GmbH- Germany) was used. Two expert manual therapist were involved to perform two 3D mobilizations (extension- axial left rotation and extension-axial right rotation) at the C1-C2 level to estimate the intra- and inter- reliability. Also C0-C1 was considered. It was also compared the values of left and right side directed 3D mobilizations.

Results: The results showed few differences between the parameters, probably due to some intra-operators factors and, thus, an intra-operator reliability could be assumed especially for the C0-C1 segment, compared to C1-C2 level. On the other hand, analyzing the inter-operators values, several differences have been demonstrated, that interfer with the general idea of an inter-operators reliability for both C0-C1 and C1-C2. Regarding to the comparison of the right side and left side of 3D mobilizations, results shows an acceptable intra-operators reliability and a poor inter-operators reliability at both the segment.

Conclusion: This thesis shows that it is possible to reach, with the manual fixation, an intra-operator reliability, allowing to maintain an acceptable consistence of the 3D mobilizations effects, probably due to the two operator's expertise. It has been demonstrated also fair reproducibility of the manual fixation techniques, that seems to be greater in the intra-operators condition. The inter operators reliability resulted fair in these two targets.

This work is formatted according to the Italian Journal of Physiotherapy (IJP) author's guidelines.

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List of Abbreviations

X:Flexion-Extension axis;

Y:Axial Rotation axis;

Z:Lateral bending axis;

Range X:quantity of degrees between the “Max” and the “min” regarding to extension movement;

Range Y:quantity of degrees between the “Max” and the “min” regarding to rotation movement;

Range Z: quantity of degrees between the “Max” and the “min” regarding to lateral bending movement;

Min X:minimum value of extension movement;

Min Y:minimum value of rotation movement;

Min Z: minimum value of lateral bending movement;

Max X: extreme movement in degrees of extension;

Max Y: extreme movement in degrees of rotation;

Max Z: extreme movement in degrees of lateral bending;

Cor: cross-correlation between axial rotation and lateral bending motions;

Ratio: relative amount between axial rotation and lateral bending motions;

EL: extension-left axial rotation;

ER: extension-right axial rotation;

C0: occiput

C1: Atlas

C2: Axis;

3D: Three dimensional;

df: Degree of freedom;

sd: standard deviation;

cc: cross-correlation;

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1. INTRODUCTION

The cervical spine, characterized by particular biomechanics, has been poorly studied with respect to lumbar spine, although representing one of the most common reasons of patient’s complains. Considering this, an increasing number of researchers are currently focused on analyzing the mechanisms underlying the cervical spine function and, in particular, on the best way to solve patient's problems by the use of manual mobilizations. To demonstrate these aspects, some authors are attempting to study the cervical spine from several points of view, for example, its correlation with posture. Some authors, studied the correlation between 3D movements and posture, comparing it to the initial movement or to specific clinical situations[1, 2]. Other researchers, as Trott et al., focused on the relationship between age and gender, and cervical mobility[3]. To investigate this last aspect, researchers have been arguing on which type of movements have to be studied, according to 2D aspects or 3D aspect of the cervical mobility[4-7]. Regarding to the 3D intersegmental mobility, used by manual therapists, few studies have been conducted in order to understand the real component of the cervical motion as well as the analysis of the kinematic behind the movement. Several authors, during their studies, have to consider the coupled motion pattern as a part that cannot be disregarded from the movement. Some researchers chose to study these components *in vivo*, in order to comparing their results as close as possible to the real condition[8-10], or *in vitro* in order to understand what really occurs in the upper cervical spine without any interferences due to the soft tissues components[11-17]. The aim of understanding the characteristics of the movement, with all the coupled motions, is important to standardize the real movement of the upper cervical spine. Thus, allows to explain the contrasting results deriving from the high variability of movement, that is presented by the superior tract of cervical spine respect to the lower one[18] or, simply, from the different way of treating the specimens spine[19]. An opportunity to achieve this goal is represented by the study of the intra- and inter-raters reliability. Cattrysse et al. already investigated this aspect and the reproducibility in a test-retest situation applied to the upper cervical spine[14, 15]. Although this aspect could be considered questionable, the necessity to investigate on this condition is fastened to the probable impact on the clinical situations.

This thesis aims to provide an *in vitro* experimental study, that, through three dimensional mobilizations recorded by an ultrasound device (extension and axial left rotation; extension and axial right rotation), may demonstrate a standardization of the C1-C2 behavior firstly, and C0-C1 then.

The purpose of this study is to evaluate the intra- and inter- examiners reliability and the reproducibility of the manual fixation, exerted on the 3D mobilizations.

The experimental part of this study has been performed in 2006 and includes Method and Material of the research of Cattrysse et al. (2007)[15].

Table 1. Methods and subjects of mentioned studies in literature

Amiri[4]	15 subject-six males and nine females-	In vivo,3-D space Fastrak
Cattrysse[11]	Six spinal specimens- five embalmed and one fresh-	In vitro, 'Flock of birds': electromagnetic tracking system
Cattrysse[12]	Five embalmed and one fresh	In vitro, 'Flock of birds': Electromagnetic tracking device
Cattrysse[13]	Nine embalmed and one fresh	In vitro, 'Flock of birds': Electromagnetic tracking device
Cattrysse[16]	Twenty fresh human cervical spine	In vitro, adapted Zebris CMS20, ultrasound motion tracking
Cattrysse[14]	Twenty fresh frozen human cervical specimens	In vitro, Zebris CMS-20 ultrasound-based tracking system
Cattrysse[15]	Twenty un-embalmed cervical spine specimens	In vitro, Zebris CMS20 ultrasound-based tracking system.
Dugailly[17]	10 unembalmed cervical specimens	In vitro, Computerized tomography
Dugailly[20]	10 unembalmed cervical specimens	In vitro, Computerized tomography
Edmondston[1]	30 asymptomatic subjects	In vivo, Spin T three-dimensional goniometer
Ishii[8]	Ten healthy volunteers	In vivo, MRI
Ishii[9]	Fifteen healthy volunteers	In vivo, MRI
Ishii[10]	Twelve healthy volunteers	In vivo, MRI
Karthu[7]	20 asymptomatic individuals	In vivo, MRI
Trott[3]	60 female and 60 male asymptomatic volunteers	In vivo, 3 SPACE Isotrak system
Gelalis[6]	Ten asymptomatic male volunteers	In vivo, Magnetic tracking device (MTD) and inclinometers
Wang[5]	40 asymptomatic young adults	In vivo, Zebris ultrasound-based system(CMS) ;
Wilke[19]	Six 16 week old calf spines	In vitro, 3D Goniometer

2. METHOD AND MATERIAL

2.1 Specimens

To test the hypothesis of this thesis, regarding the reproducibility of the manual fixation and the kinematic analysis, twenty fresh human spinal specimens were studied, whose 9 male and 11 females. In particular, the occiput, the cervical segments and the first two thoracic vertebrae have been included. The mean age of the specimens was 80 years (± 11 years) with a range from 59 to 97 years. During the procedures of this experimental study, the room temperature was kept controlled between 15° and 20° with a humidity rate above 60% to prevent the dehydration of the specimens.

2.2 Instruments

For the administration of the manual technique for the specimens, an adapted Zebris CMS20 ultrasound-based motion tracking system (Zebris Medical GmbH- Germany) was used. The accuracy of the system has been studied using a single hinge phantom. One transmitter and the receiver of the device were mounted on a high accuracy rotary stage (Time and Precision Ltd., Baringstoke,, England) making possible to produce an angular displacements with an accuracy of 0,02 per step. The standard deviations can be used as an indicative measure of error. An overall deviation of 0,04° occurs on the main axis on a total measurement range of 75° of motion of the phantom. Standard deviations of 0,25° and 0,29° occur on the other axes. Differences between the performed angular displacements and the angles calculated can be partly attributed to cross-talk effects. After applying a correction technique for misalignment between the axis of the phantom and the reference frame defined during the set-up of the Zebris system based on an optimization technique, these standard deviations for the real and the measured angles can be reduced to 0,20° and 0,13°. The system, thus, reproduces the angles of movement with an accuracy of less than 0,1° for the main motion component and 0,2° for the coupled components. Data, resulting unprocessed, were recorded as ASCII files and were calculated with Mathcad professional software.

2.3 Methods

As it is important to compute kinematic behaviour of the segments, preventing limitation of movement and uncontrolled coupled motions due to the fixation of the ultrasound system, dissection of the skin, subcutaneous tissue and muscles have been exerted, leaving muscular insertions and ligaments intact. This procedure could modify results due to biomechanical changes of muscles. It has, however, been demonstrated that the biomechanical properties of the tendons and ligaments do not change with the conservation by freezing. Specially fabricated fixation tools were inserted in the parietal part of the occiput, the transverse process of the atlas and the transverse process of axis. The transmitters and receiver of the Zebris system were mounted on these fixation tools. The optimal positioning of the device was controlled for every specimen before the start of the mobilizations. Fixation pins were drilled cross-linked through the corpus of the second thoracic vertebra (T2). The specimen was mounted in a wooden frame by these fixation pins. In this way, the specimen was positioned as if the subject was in a supine position on an examination table. The preliminary dissection and the optimal positioning of the fixation tools allows free mobility of the cervical spine through full range of motion in axial rotation, lateral bending, flexion-extension and combined directions. During the procedure, two complex mobilizations were exerted, that were composed firstly by an extension and left rotation, and secondly by an extension and right rotation. Both were performed with a manual fixation, fastening the axis while the atlas and the atlanto-occipital joint were moved. In this study was also considered the movement of this latter articulation during the testing and all the movements were performed three times consecutively by two physical therapist with several years of experience in manual therapy in a test-retest situation. The test-retest order was assigned randomly for the two investigators that were also blinded from the analysis data of the system during testing. One of the examiners was experienced in the examined techniques. The other usually performed similar but not identical mobilizing techniques and familiarized with the specific techniques described above before the testing period. Both examiners performed a trial with a feedback of the tracking system in a test-retest situation on one specimen to familiarize with the techniques and the test set-up.

2.4 3D angles of motion

The angles of movement used in the present analysis are the angles reproduced from the Zebris-winbiomechanics software. A graphical representation of the calculated angles has been presented by Wang et al.

The definition of the local reference frame used by the Zebris system is based on three markers: L, R and F. The point L, referred to left, was chosen as marker inserted on the left transverse process of the axis; the point R, referred to right, was inserted on the right transverse process; the point F, referred to the front, centrally on the anterior side of the corpus.

Unfortunately, the international Society of Biomechanics (ISB), even if has defined the local reference frame for middle and lower cervical spine, couldn't provide the same frame for the upper cervical spine because, due to the particular configuration of upper cervical vertebrae and the type of experiment, the centre of corpus could not be fixed. Despite of this, the local reference frame was established and the labelling of the axes was chosen in congruency with the ISB-guidelines. The axes are defined as follows:

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

The direction of the Z-axis was reversed to create a right handed orthogonal reference frame. It's relevant to explain that the sign of the angles around the Y-axis was changed. In this way an axial rotation and a lateral bending to the same side are indicated by the same sign, i.e. left and right, respectively, represented by – and + signs.

2.5 Data analysis of motion coupling patterns

In this experimental study was considered the coupled lateral bending associated with the main extension-axial rotation. Thus six parameters were used to objectify and describe the behaviour of all these components. Especially have beenheld in consideration:

- Max X, Max Y, Max Z: they are the extreme position of each axis (respectively extension, axial rotation and lateral bending);
- Min X, Min Y, Min Z: representing the starting point of each axis;

As well as these values, cross-correlation (CC) and ratio were also considered. Particularly, the first one is a measure of similarity between the two function in a lag time and, in this case, it was applied to axial rotation and the coupled lateral bending. It can be considered as the equivalent of Pearson Correlation Coefficient. The Ratio between the axial rotation and the coupled lateral bending can be considered as the relative amount between the extreme position of axial rotation and lateral bending motions.

2.6 Statistical Analysis

To perform all the statistical analysis the statistical software SPSS was used. During the first phase, the procedure had the goal to understand which kind of distribution was represented by the data and so a Kolmogorov-Smirnoff goodness-of-fit test was used, permitting to also calculate the descriptive statistics. The reproducibility of the results was considered analysing the differences between test and retest results. Then an analysis of variance (ANOVA) was used to show the differences between paired data of measurement resulting by each mobilization technique. Then, a paired Student's T-test between consecutive measurements was performed for the parameters that had presented a statistical significant ANOVA. Significance was tested using the 5% rejection level ($p<0.05$).

3. RESULTS

3.1 Intra- and inter- examiners reliability

To evaluate the test reliability and to analyze the variance between the four different groups of data, in order to estimate any differences between the two operators in a test-retest situation, an ANOVA test was performed (table 2).

Table 2. Values statistical significant and not significant computed by ANOVA

	EL 01	ER 01	EL 12	ER 12
RANGE X	0,115	0,239	**0,001****	0,264
RANGE Y	0,564	**0,040***	**0,030***	**0,000****
RANGE Z	**0,007***	**0,034***	0,905	**0,043**
MIN X	0,439	0,713	**0,045***	0,654
MIN Y	0,125	**0,036***	0,991	**0,000****
MIN Z	0,561	0,551	0,334	0,808
MAX X	0,458	0,389	0,169	0,331
MAX Y	0,277	0,181	0,196	0,524
MAX Z	0,322	0,066	0,728	0,178
COR	0,995	0,153	**0,002***	0,529
RATIO	0,204	0,893	0,409	**0,032***

Range X:quantity of degrees between the "Max" and the "min" regarding to extension movement; Range Y:quantity of degrees between the "Max" and the "min" regarding to rotation movement; Range Z: quantity of degrees between the "Max" and the "min" regarding to lateral bending movement; Min X:minimum value of extension movement; Min Y:minimum value of rotation movement; Min Z: minimum value of lateral bending movement; Max X: extreme movement in degrees of extension; Max Y: extreme movement in degrees of rotation; Max Z: extreme movement in degrees of lateral bending; Cor: cross-correlation between axial rotation and lateral bending motions; Ratio: relative amount between axial rotation and lateral bending motions; EL: extension-left axial rotation; ER: extension-right axial rotation; 01: C0-C1; 12: C1-C2; *: p≤ 0,05; **: p ≤ 0,01;

Considering the occipital-atlanto joint, it has been observed that the values, regarding the range Z of the extension- left rotation (EL) and those representing the range Y and Z and min Y of the extension- right rotation (ER) resulted statistically significant. On the contrary, the atlanto-axial joint showed several statistically significant values, even if the components of the extreme movement(Max x,y and z), exerted during these complex mobilizations, did not shows significant differences. Then, to obtain a better definition of the differences and in order to compare values, all those variables that resulted statistically significant with the ANOVA test were assembled in two groups and, to check the test-retest reliability, a Student t-test was performed (six pairs: T1-T2,T1-R1,T1-R2,T2-R1,T2-R2,R1-R2) (table 3).

Table 3. Significance in student's T-test in the parameters resulted statistically significant in the ANOVA

Parameters	T1-T2	T1-R1	T1-R2	T2-R1	T2-R2	R1-R2
M range Z EL 01	Not sign	**Sign 0,013**	**Sign 0,007**	Not sign	Not sign	Not sign
M range Y ER 01	Not sign	Not sign	Not sign	Not sign	**Sign 0,022**	Not sign
M range Z ER 01	Not sign	Not sign	Not sign	**Sign 0,028**	**Sign 0,019**	Not sign
M min Y ER 01	**Sign 0,034**	Not sign	**Sign 0,001**	Not sign	Not sign	Not sign
M range X EL 12	**Sign 0,033**	**Sign 0,022**	**Sign 0,017**	**Sign 0,002**	**Sign 0,000**	Not sign
M range Y EL 12	Not sign	Not sign	Not sign	**Sign 0,046**	Not sign	Not sign
M min X EL 12	**Sign 0,033**	Not sign	Not sign	**Sign 0,005**	**Sign 0,003**	Not sign
M Cor EL 12	Not sign	**Sign 0,010**	**Sign 0,014**	**Sign 0,031**	Not sign	Not sign
M range Y ER 12	Not sign	**Sign 0,002**	**Sign 0,001**	**Sign 0,011**	**Sign 0,002**	Not sign
M range Z ER 12	Not sign	Not sign	Not sign	Not sign	Not sign	Not sign
M min Y ER 12	Not sign	**Sign 0,003**	**Sign 0,008**	**Sign 0,017**	**Sign 0,015**	Not sign
M Ratio ER 12	Not sign	Not sign	Not sign	Not sign	**Sign 0,005**	Not sign

Range X:quantity of degrees between the "Max" and the "min" regarding to extension movement; Range Y:quantity of degrees between the "Max" and the "min" regarding to rotation movement; Range Z: quantity of degrees between the "Max" and the "min" regarding to lateral bending movement; Min X:minimum value of extension movement; Min Y:minimum value of rotation movement; Min Z: minimum value of lateral bending movement; Max X: extreme movement in degrees of extension; Max Y: extreme movement in degrees of rotation; Max Z: extreme movement in degrees of lateral bending; Cor: cross-correlation between axial rotation and lateral bending motions; Ratio: relative amount between axial rotation and lateral bending motions; EL: extension-left axial rotation; ER: extension-right axial rotation; 01: C0-C1; 12: C1-C2; *: p≤ 0,05; **: p ≤ 0,01;

These results showed few differences between the parameters, probably due to some intra-operators factors and, thus, an intra-operator reliability could be assumed. On the other hand, analyzing the inter-operators values, several differences have been demonstrated, that interfer with the general idea of an inter-operators reliability.

Then, in case of further statistically significant differences, it is calculated, with the analysis of differences between means and, then, compared to the statistical descriptive, the importance of the significant values. It results that only in the atlanto-axial joint, mobilized with an extension-left rotation, there are the greater differences, as shown in the table 4:

Table 4. Differences between means

Parameters	Mean	Standard Deviation
Diff.T1R1EL01 range z	-4,4527	4,89727
DiffT1R2EL01 range z	-3,7846	4,16219
Diff.T2R2ER01 range y	-2,6413	3,955
Diff.T2R1ER01 range z	-4,4442	6,10023
Diff.T2R2ER01 range z	-3,5267	5,16380
Diff.T1T2ER01 min y	3,6058	5,16873
Diff.T1R2ER01 min y	6,2423	5,30151
DiffT1T2EL12 range x	-3,3008	4,68993
Diff.T1R1EL12 range x	5,0436	6,20162
Diff.T1R2EL12 range x	4,5923	5,97401
Diff.T2R1EL12 range x	8,6800	7,35143
Diff.T2R2EL12 range x	8,9987	6,91998
Diff.T2R1EL12 range y	3,9483	6,08876
Diff.T1T2EL12 min x	6,0367	8,57209
Diff.T2R1EL12 min x	-5,3650	5,34867
Diff.T2R2EL12 min x	-4,6400	5,02912
Diff.T1R1EL12 cor	-0,9173	0,95282
Diff.T1R2EL12 cor	-0,6446	0,80552
Diff.T2R1EL12 cor	-0,6875	0,96154
Diff.T1R1ER12 range y	-14,1070	10,08641
Diff.T1R2ER12 range y	-16,9508	13,57285
Diff.T2R1ER12 range y	-12,7150	14,35535
Diff.T2R2ER12 range y	-13,9707	14,45983
Diff.T1R1ER12 min y	13,9130	10,87332
Diff.T1R2ER12 min y	30,10	12,79354
Diff.T2R1ER12 min y	12,4150	15,25916
Diff.T2R2ER12 min y	9,0987	12,66527
Diff.T2R2ER12 ratio	-1,9180	2,24876

3.2 Comparison of the left and right side directed mobilizations

The procedures to demonstrate the reproducibility of the manual fixation are the same used for the intra-inter reliability, even if just the MAX and MIN values of the complex mobilization were considered. In particular, a comparison between the left and the right side of the rotation, associated with the other components was performed. ANOVA data shown in the table 5 :

Table 5. Statistically significant values from ANOVA during the comparison between left and right side directed mobilizations

	Max X	Max Y	Max Z	Min X	Min Y	Min Z
EL 01	0,458	0,277	0,322	0,439	0,125	0,561
ER 01	0,470	0,181	0,066	0,713	**<u>0,036</u>**	0,551
EL 12	0,169	0,196	0,728	**<u>0,045</u>**	0,991	0,334
ER 12	0,331	0,524	0,178	0,654	**<u>0,000</u>**	0,808

Range X:quantity of degrees between the “Max” and the “min” regarding to extension movement; Range Y:quantity of degrees between the “Max” and the “min” regarding to rotation movement; Range Z: quantity of degrees between the “Max” and the “min” regarding to lateral bending movement; Min X:minimum value of extension movement; Min Y:minimum value of rotation movement; Min Z: minimum value of lateral bending movement; Max X: extreme movement in degrees of extension; Max Y: extreme movement in degrees of rotation; Max Z: extreme movement in degrees of lateral bending; Cor: cross-correlation between axial rotation and lateral bending motions; Ratio: relative amount between axial rotation and lateral bending motions; EL: extension-left axial rotation; ER: extension-right axial rotation; 01: C0-C1; 12: C1-C2; *: $p \leq 0,05$; **: $p \leq 0,01$

The results appears without any statistically significant differences in the maximum values and few differences, that regard to the minimum values. For this reason, it was used t-test for these latter results, showing differences already in the inter operator values.

4. DISCUSSION

This study was performed as an *in vitro* analysis to analyze the reproducibility of the manual fixation intra and inter-operators and to verify the consistency of the movement, considering the opposite side of two rotation. This goal has been reached by using Zebris system, an ultrasound device and comparing the test-retest situation. Such system was chosen because there are several studies showing a great reliability on measuring especially three dimensional movements[5]. Despite this, some movements were not calculated because of technical problems (bad signal received, etc) and one specimen was dropped out because presented an anatomical variant. To demonstrate the purpose of this study, the ANOVA analysis was performed on values regarding the movements, deriving from the complex mobilizations, and it has been demonstrated that, at atlanto axial joint level, there are more statistically differences than those in the atlanto-occipital joint. Then, student T-test was performed to understand which factor could cause these differences (intra/inter-operator). This analysis underlines few contrasting results, allowing to realize a good agreement with the intra-operator values, and several statistically significant differences, regarding to the inter- operator computation. Indeed, only 3 out of 12 parameters, regarding the first operator, were statistically significant and there were no differences, regarding the values of the second operator. These analysis showed an acceptable level of intra-operator reliability. On the other hand, several relevant results have been observed in the inter-operator conditions, providing, thus, a poor agreement between the two raters. This findings are agreement to some previous studies [14, 15] The relevant intra-operator reliability could be explained by the two raters' expertise and their familiarity to manual techniques while the poor inter-operators agreement could be due to the different control of the mobilized segment by the therapists, who perform a 3D mobilization in respect to a planar mobilization. The same analysis was performed to demonstrate the reproducibility, considering the left and right rotation and verifying if it is possible to reach the same values of movements. By the analysis of the Max X, Y, Z and min X, Y, Z with ANOVA, it is clear that the movements can be reproduced because only few differences have been found in the minimum values. Student T-test confirmed the greater intra-operator agreement than the inter-operator's one. Also these results are in according to previous studies [14, 15]. The limitations of this study are due to two reasons. Firstly, the results derived by the performances of two expert therapists and so they could not be extended to all the operators. Secondly, this is an *in vitro* study and the deriving findings should be restricted to this situation. However, there are few studies about the upper cervical spine and, most of them, are focused only on the planar mobilization. On the contrary, this thesis studied the reproducibility of the manual fixation, not only at the upper cervical level using a 3D mobilization, but also using Zebris and involving in the inter-operators conditions.

5. Conclusion

This thesis shows that it is possible to reach, with the manual fixation, an intra-operator reliability, allowing to maintain an acceptable consistence of the 3D mobilizations effects. Even if this study demonstrates these results, there are many factors that could interfere with these findings as the high degree of anatomical variability of the upper cervical spine as well as the familiarity with the manual therapy technique, that is not easily achievable. It has been demonstrated also fair reproducibility of the manual fixation techniques, that seems to be greater in the intra-operators condition. Further *in vivo* studies are needed to validate the results in order to make these findings as close as possible to the real patient's condition.

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Addenda

Addendum 1: Literature research

To perform this in vitro study, Pubmed database was used to search scientific articles, related to the subject of the present study. Several key words and synonyms were combined, including mesh terms, to find citations and, then, examinated. The PICO model was used to create there combinations.

The Key word were:

-(P)"Upper cervical spine": atlanto-axial joint, atlanto-occipital joint, head, neck, cervical vertebrae, cranio cervical joint, upper cervical vertebrae;

-(I)" Segmental": in vivo, in vitro,

-(CO)"Kinematics" : motion, kinematics analysis, three dimensional biomechanics, manual therapy, 3D mobilizations, coupled movements, coupled motions, coupling behavior;

The limits, that were set up:

-Languages: English, French

-Species: human;

-Age: adult +19.

Results:

In the Pubmed database, at first, 43 articles were found. After the reject by the title and by the abstract, 20 articles were included in the present study.

Addendum 2: Descriptive statistic

Tab 2.1. Descriptive statistic of parameters in extension-axial left rotation of C0-C1

Statistiche descrittive					
	N	Minimo	Massimo	Media	Deviazione std.
T1EL01Mrangex	15	,00	36,85	4,9853	8,96714
T2EL01Mrangex	16	,13	9,32	3,6579	2,68105
R1EL01Mrangex	15	,00	11,01	5,2133	3,19143
R2EL01Mrangex	17	,97	13,68	5,4447	3,80027
T1EL01Mrangey	14	1,00	9,05	4,1193	2,47042
T2EL01Mrangey	16	1,61	15,12	4,8219	3,55529
R1EL01Mrangey	14	1,05	14,71	5,3364	4,00809
R2EL01Mrangey	17	1,07	13,80	5,6500	3,38390
T1EL01Mrangez	14	1,07	14,10	5,5850	3,71695
T2EL01Mrangez	16	2,34	13,37	6,2513	3,44549
R1EL01Mrangez	14	1,56	20,20	9,3421	4,70570
R2EL01Mrangez	17	4,49	15,26	8,9253	3,27884
T1EL01Mminx	14	-4,60	4,61	-,4929	2,24378
T2EL01Mminx	16	-16,44	4,73	-1,8650	5,17043
R1EL01Mminx	14	-9,55	3,42	-3,0943	3,89561
R2EL01Mminx	17	-21,29	5,06	-3,6624	7,06725
T1EL01Mminy	14	-6,07	6,46	-,3536	3,52476
T2EL01Mminy	16	-9,98	5,77	-3,2813	3,98050
R1EL01Mminy	14	-16,08	13,76	-2,6514	6,70146
R2EL01Mminy	17	-24,43	10,54	-5,3924	7,52146
T1EL01Mminz	14	-17,75	11,37	-3,8786	7,86808
T2EL01Mminz	16	-11,79	5,89	-2,5419	4,96035
R1EL01Mminz	14	-19,29	-,90	-6,5136	6,06192
R2EL01Mminz	17	-13,87	6,85	-3,0729	5,22089
T1EL01MMAXx	14	-2,62	37,10	4,8486	9,70445
T2EL01MMAXx	16	-9,35	6,90	1,9731	4,04999
R1EL01MMAXx	14	-3,36	8,03	2,4914	2,65417
R2EL01MMAXx	17	-18,74	12,74	1,7824	7,01153
T1EL01MMAXy	14	-3,34	14,75	3,7657	4,87881
T2EL01MMAXy	16	-6,18	9,87	1,5406	3,95399
R1EL01MMAXy	14	-7,83	15,86	2,6850	6,70182
R2EL01MMAXy	17	-18,62	17,21	,2947	7,83738
T1EL01MMAXz	14	-9,02	19,22	1,7064	8,05455
T2EL01MMAXz	16	-7,78	18,02	3,7094	7,55820
R1EL01MMAXz	14	-7,25	12,37	2,8286	5,92554
R2EL01MMAXz	17	-8,70	17,66	5,8524	6,76989
T1EL01Mcor1	14	-,98	,94	-,4700	,64525
T2EL01Mcor	16	-,99	,96	-,6031	,61788
R1EL01Mcor	14	-,99	,71	-,5464	,56690
R2EL01Mcor	17	-,98	,84	-,5459	,52304
T1EL01Mratio1	14	,24	2,35	,8586	,55139
T2EL01Mratio	16	,19	2,13	,7981	,48650
R1EL01Mratio	14	,16	1,60	,5857	,47511
R2EL01Mratio	17	,12	1,44	,5729	,38529
Validi (listwise)	10				

Table 2.2 Descriptive statistic of parameters in extension-axial right rotation of C0-C1

Statistiche descrittive	N	Minimo	Massimo	Media	Deviazione std.
T1ER01Mrangex	14	2,02	36,85	6,7900	9,06350
T2ER01Mrangex	16	,85	12,47	3,8163	2,81801
R1ER01Mrangex	14	,59	11,59	5,2963	3,29092
R2ER01Mrangex	17	1,63	13,60	6,3465	3,74027
T1ER01Mrangey	14	1,58	15,84	5,1507	4,14874
T2ER01Mrangey	16	,86	15,70	4,9819	4,51533
R1ER01Mrangey	14	1,77	16,21	5,8293	4,34422
R2ER01Mrangey	17	2,55	12,76	7,7600	3,47434
T1ER01Mrangez	14	,71	17,85	7,2100	5,34762
T2ER01Mrangez	16	1,05	12,40	5,4925	3,61083
R1ER01Mrangez	14	1,26	16,58	9,1943	4,80697
R2ER01Mrangez	17	1,89	18,01	8,7800	3,84558
T1ER01Mminx	14	-4,63	2,77	-,8357	2,49662
T2ER01Mminx	16	-19,21	3,85	-1,8331	5,32716
R1ER01Mminx	14	-9,71	1,08	-3,5621	3,21598
R2ER01Mminx	17	-21,48	1,57	-5,2318	6,85215
T1ER01Mminy	14	-9,37	8,89	-,3014	4,70566
T2ER01Mminy	16	-10,36	2,57	-3,6438	4,09060
R1ER01Mminy	14	-18,58	6,23	-3,7300	6,19291
R2ER01Mminy	17	-30,51	5,98	-7,1741	7,64295
T1ER01Mminz	14	-20,81	7,20	-5,9714	7,24081
T2ER01Mminz	16	-11,49	10,25	-2,3750	5,31556
R1ER01Mminz	14	-15,74	3,71	-5,0436	5,45350
R2ER01Mminz	17	-14,21	1,24	-3,6394	4,30580
T1ER01MMAXx	14	,01	37,10	5,9543	9,49859
T2ER01MMAXx	16	-15,70	11,52	1,9831	6,04403
R1ER01MMAXx	14	-3,67	10,67	2,6964	3,56394
R2ER01MMAXx	17	-14,96	12,78	1,1147	6,08788
T1ER01MMAXy	14	-2,15	19,12	4,8493	6,09348
T2ER01MMAXy	16	-8,20	10,74	1,3381	3,96369
R1ER01MMAXy	14	-6,36	16,26	2,0993	5,01190
R2ER01MMAXy	17	-17,75	16,96	,5859	6,87277
T1ER01MMAXz	14	-10,03	11,54	1,2386	5,94449
T2ER01MMAXz	16	-8,35	14,45	3,1238	6,79273
R1ER01MMAXz	14	-7,34	12,51	4,1507	6,80191
R2ER01MMAXz	17	-5,51	17,06	5,1406	6,02022
T1ER01Mcor	14	-1,00	,99	-,5479	,62175
T2ER01Mcor	16	-,98	,69	-,5188	,54224
R1ER01Mcor	14	-,99	,99	-,5014	,62832
R2ER01Mcor	17	-1,00	,34	-,8618	,31617
T1ER01Mratio	14	,11	4,44	1,3486	1,43352
T2ER01Mratio	16	-,35	5,26	1,1769	1,31921
R1ER01Mratio	14	,12	10,27	1,4579	2,67141
R2ER01Mratio	17	,21	4,13	1,2947	1,12138
Validi (listwise)	9				

Table 2.3 Descriptive statistic of parameters in extension-axial left rotation of C1-C2

Statistiche descrittive					
	N	Minimo	Massimo	Media	Deviazione std.
T1EL12Mrangex	14	5,34	23,93	11,8943	5,75347
T2EL12Mrangex	16	8,60	29,61	15,7631	6,42851
R1EL12Mrangex	14	3,19	16,67	8,7971	4,82601
R2EL12Mrangex	17	1,99	16,95	6,9388	3,55964
T1EL12Mrangey	14	3,15	37,50	19,0714	8,63537
T2EL12Mrangey	16	9,22	40,65	24,4013	8,98400
R1EL12Mrangey	14	12,59	35,98	24,4557	6,94178
R2EL12Mrangey	17	15,95	36,35	24,4024	5,08694
T1EL12Mrangez	14	1,38	23,47	11,3671	6,54594
T2EL12Mrangez	16	4,72	35,71	13,1788	7,95729
R1EL12Mrangez	14	3,49	33,49	11,6457	8,01078
R2EL12Mrangez	17	2,28	18,03	9,9588	4,29456
T1EL12Mminx	14	-16,53	9,23	-4,6107	7,87650
T2EL12Mminx	16	-18,82	,92	-8,8400	5,54426
R1EL12Mminx	14	-19,47	6,64	-4,9357	6,55932
R2EL12Mminx	17	-25,16	2,68	-5,5694	6,48693
T1EL12Mminy	14	-22,98	11,56	-4,3129	8,01991
T2EL12Mminy	16	-27,35	7,29	-6,5806	8,54272
R1EL12Mminy	14	-22,00	8,43	-5,4064	8,10962
R2EL12Mminy	17	-15,86	8,62	-6,1247	6,09906
T1EL12Mminz	14	-19,51	4,41	-6,9079	7,32756
T2EL12Mminz	16	-29,84	3,13	-6,6081	8,25390
R1EL12Mminz	14	-11,11	5,47	-4,4600	5,87597
R2EL12Mminz	17	-20,45	9,37	-2,7465	7,69540
T1EL12MMAXx	14	-2,59	26,62	7,2800	7,48819
T2EL12MMAXx	16	-4,06	27,99	6,9231	8,55309
R1EL12MMAXx	14	-9,45	12,15	3,8614	5,55366
R2EL12MMAXx	17	-15,15	7,82	1,3694	5,63115
T1EL12MMAXy	14	-6,01	35,74	14,7586	10,49471
T2EL12MMAXy	16	-4,38	36,23	17,8206	12,81992
R1EL12MMAXy	14	1,37	39,09	19,0493	10,75746
R2EL12MMAXy	17	9,33	36,47	18,2776	7,64823
T1EL12MMAXz	14	-9,96	20,80	4,4593	8,35002
T2EL12MMAXz	16	-4,60	18,84	6,5706	7,91441
R1EL12MMAXz	14	-5,70	22,38	7,1857	7,46153
R2EL12MMAXz	17	-9,48	19,81	7,2124	8,59126
T1EL12Mcor	14	-,99	,99	-,3836	,75996
T2EL12Mcor	16	-,99	,98	-,2013	,85277
R1EL12Mcor	14	-,91	,98	,3750	,63526
R2EL12Mcor	17	-,97	,98	,1635	,73227
T1EL12Mratio	14	,60	5,45	2,4157	1,59889
T2EL12Mratio	16	1,03	7,32	2,8181	1,62453
R1EL12Mratio	14	,87	12,79	4,0086	3,17950
R2EL12Mratio	17	1,52	14,39	4,0288	3,17312
Validi (listwise)	10				

Table 2.4 Descriptive statistic of parameters in extension-axial right rotation of C1-C2

Statistiche descrittive					
	N	Minimo	Massimo	Media	Deviazione std.
T1ER12Mrangex	14	1,33	16,88	8,7314	4,66387
T2ER12Mrangex	16	3,30	26,77	10,4044	5,85363
R1ER12Mrangex	14	4,14	16,70	7,6407	3,80778
R2ER12Mrangex	17	2,00	23,44	7,8612	5,83426
T1ER12Mrangey	14	3,15	35,03	15,3514	9,49450
T2ER12Mrangey	16	1,52	36,51	15,2413	9,55683
R1ER12Mrangey	14	17,45	51,51	29,4436	8,23499
R2ER12Mrangey	17	14,88	59,53	30,3982	10,46577
T1ER12Mrangez	14	1,38	35,54	16,7371	10,70741
T2ER12Mrangez	16	2,36	21,86	13,7050	6,37193
R1ER12Mrangez	14	4,16	24,07	12,3057	5,30553
R2ER12Mrangez	17	4,10	37,45	13,2212	8,18841
T1ER12Mminx	14	-7,72	10,84	-1,4129	4,67434
T2ER12Mminx	16	-7,14	2,48	-2,8675	2,92509
R1ER12Mminx	14	-17,09	3,59	-2,4207	4,97948
R2ER12Mminx	17	-22,92	2,79	-5,3018	6,61954
T1ER12Mminy	14	-30,25	4,04	-10,2864	8,78677
T2ER12Mminy	16	-27,41	,01	-11,6913	8,15318
R1ER12Mminy	14	-42,44	-13,29	-24,2736	8,71723
R2ER12Mminy	17	-39,90	-4,99	-20,6141	10,81931
T1ER12Mminz	14	-17,30	2,95	-5,5421	4,99894
T2ER12Mminz	16	-13,36	1,79	-4,4500	4,64313
R1ER12Mminz	14	-15,79	10,16	-3,3536	6,83553
R2ER12Mminz	17	-25,89	20,07	-2,6935	10,95289
T1ER12MMAXx	14	-,87	17,08	7,3186	4,63080
T2ER12MMAXx	16	-,01	29,25	7,5369	7,31223
R1ER12MMAXx	14	-7,67	17,71	5,2200	5,84734
R2ER12MMAXx	17	-10,15	16,84	2,5594	5,87313
T1ER12MMAXy	14	-8,20	23,54	5,0650	9,21258
T2ER12MMAXy	16	-3,14	17,33	3,5500	5,63429
R1ER12MMAXy	14	-8,71	14,23	5,1700	6,77464
R2ER12MMAXy	17	-7,10	32,43	9,7841	11,36638
T1ER12MMAXz	14	-,61	30,02	11,1950	9,41744
T2ER12MMAXz	16	-1,40	21,71	9,2550	6,84129
R1ER12MMAXz	14	-5,44	27,81	8,9521	10,23966
R2ER12MMAXz	17	-12,40	44,53	10,5276	13,26696
T1ER12Mcor	14	-,99	,78	-,6643	,51716
T2ER12Mcor	16	-,99	,81	-,7406	,45359
R1ER12Mcor	14	-,98	,99	-,6243	,66849
R2ER12Mcor	17	-,98	,88	-,5906	,60142
T1ER12Mratio	14	,14	8,98	2,1171	2,91590
T2ER12Mratio	16	,06	9,13	2,1644	2,66755
R1ER12Mratio	14	1,38	9,34	3,1293	2,29959
R2ER12Mratio	17	,69	12,37	4,0171	2,84628
Validi (listwise)	9				