Global and regional kinematics of the cervical spine during upper cervical spine manipulation: A reliability analysis of 3D motion data

Pierre-Michel Dugailly, a, b, *, Benoît Beyer, a, b, c, Stéphane Sobczak, a, b, Patrick Salvia, c, Véronique Feipel a, b, c

* Research Unit in Osteopathy, Faculty of Motor Sciences, Université Libre de Bruxelles (ULB), Brussels, Belgium
b Laboratory of Functional Anatomy, Faculty of Motor Sciences, Université Libre de Bruxelles (ULB), Brussels, Belgium
c Laboratory of Anatomy, Biomechanics and Organogenesis (LABO), Faculty of Medicine, Université Libre de Bruxelles (ULB), Brussels, Belgium

A R T I C L E   I N F O

Article history:
Received 31 October 2013
Received in revised form 22 April 2014
Accepted 28 April 2014

Keywords:
Manipulation
Kinematics
Upper cervical spine
Reliability

A B S T R A C T

Studies reporting spine kinematics during cervical manipulation are usually related to continuous global head–trunk motion or discrete angular displacements for pre-positioning. To date, segmental data analyzing continuous kinematics of cervical manipulation is lacking. The objective of this study was to investigate upper cervical spine (UCS) manipulation in vitro. This paper reports an inter- and intra-rater reliability analysis of kinematics during high velocity low amplitude manipulation of the UCS. Integration of kinematics into specific-subject 3D models has been processed as well for providing anatomical motion representation during thrust manipulation.

Three unembalmed specimens were included in the study. Restricted dissection was realized to attach technical clusters to each bone of interest (skull, C1–C4 and sternum). During manipulation, bone motion data was computed using an optoelectronic system. The reliability of manipulation kinematics was assessed for three experimented practitioners performing two trials of 3 repetitions on two separate days. During UCS manipulation, average global head–trunk motion ROM (±SD) were 14 ± 5°, 35 ± 7° and 14 ± 8° for lateral bending, axial rotation and flexion-extension, respectively. For regional ROM (C0–C2), amplitudes were 10 ± 5°, 30 ± 5° and 16 ± 4° for the same respective motions. Concerning the reliability, mean RMS ranged from 1° to 4° and from 3° to 6° for intra- and inter-rater comparisons, respectively.

The present results confirm the limited angular displacement during manipulation either for global head–trunk or for UCS motion components, especially for axial rotation. Additionally, kinematics variability was low confirming intra- and inter-practitioners consistency of UCS manipulation achievement.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Spinal manual techniques such as manipulation and mobilization are frequently recommended for treating mechanical cervical pain and dysfunctions. These manual therapeutic methods demonstrated comparable or better improvements of symptoms, function, quality of life and patient satisfaction compared with conventional medical management (Gross et al., 2010; Rubinstein et al., 2011). Additionally, recent studies emphasized the use of upper cervical spine (UCS) manipulation in combination with thoracic thrust manipulation for patients with mechanical cervical pain (Dunning et al., 2012).

Despite the low prevalence of accidents related to cervical manipulation (Haldeman et al., 2002), clinical risk incurred by the patient remains debated (Rubinstein, 2008) concerning reported adverse effects and serious consequences on patient morbidity (Assendelft et al., 1996). Conversely, clinical risks are much less common than those reported for some medications (Dabbs and Lauretti, 1995; Oliphant, 2004). From a biomechanical point of view, axial rotation is likely to be the main motion component implied in vertebral artery (VA) mechanical injury (Hufnagel et al., 1999). However, changes in blood flow during various axial rotation tasks are inconsistent (Quesnele et al., 2013) and other risk factors are likely to endanger the vertebral artery (Debette and Leys, 2009). Conversely, clinical risks related to cervical manipulation are much less common than those reported for some medications (Dabbs and Lauretti, 1995; Oliphant, 2004).

Kinematics of cervical spine manipulation has been widely analyzed describing various parameters such as angular
demonstrating poor inter-rater reliability. These reported findings have been clearly observed for different practitioners manipulating positions. Moreover, different manipulation kinematics of the upper cervical spine during manual cervical mobilization for in vitro conditions. They observed various segmental kinematics and coupled motion patterns for different manual techniques. Additionally, partial relationship between anatomical characteristics and kinematics during manual mobilization have been mentioned (Cattrysse et al., 2011).

On the other hand, substantial to good segmental in vitro motion reliability was demonstrated during UCS mobilization techniques (Cattrysse et al., 2009). Head–trunk kinematics and motion reliability have not been yet investigated in the literature for the cervical segment (from C0 to C7) and demonstrated a counter-rotation of the lower cervical levels with respect to the rotation side of the head. However, this study described motion during pre-positioning by extrapolating kinematics from two discrete positions and not during continuous motion. In contrast, authors (Cattrysse et al., 2007a, b) analyzed continuous segmental kinematics of the upper cervical spine during manual cervical mobilization for in vitro conditions. They observed various segmental kinematics and coupled motion patterns for different manual techniques. Additionally, partial relationship between anatomical characteristics and kinematics during manual mobilization have been mentioned (Cattrysse et al., 2011).

To date, regional or segmental cervical kinematics and motion reliability have not been yet investigated in the literature for the UCS manipulation. However, this joint complex is frequently reported as the main cervical spine area where biomechanical stresses on the vertebral artery may occur during motion. Hence, this study aims at analyzing in vitro three-dimensional global and regional kinematics of the cervical spine during UCS manipulation for different experienced practitioners, as well as at evaluating its inter- and intra-reliability.

2. Materials and methods

2.1. Study design

This study was conducted on three fresh cadavers (2 females, 1 male; age 88 ± 2 years; from the local University Willed Body Donation program). Prior to kinematics assessment, specimen’s cervical region was carefully prepared by an expert in anatomical dissection to access to the cervical vertebral segments, anteriorly and laterally. Minimal exposure was performed to avoid large invasive dissection and keep muscles intact for maintaining normal conditions as much as possible.

To measure vertebral motion displacement, technical clusters were customized and drilled through an anterior approach into several bones, the occiput (at the vertex), C1 (tip of the transverse process), C2–C4 (vertebral body) and sternum (manubrium junction) (Fig. 1). Each cluster consists in four reflective markers (diameter: 9 mm). Note that segmental motions were not restricted due to the technical clusters relative to soft tissues surrounding the system during manipulation procedure. Free motion through the full range of motion was verified after pin placement.

Concerning manipulation procedure, three practitioners (10–20 years of experience) performed three consecutive osteopathic manipulations (high velocity and low amplitude, HVLA) at the upper cervical spine using a multiple component technique. All practitioners had followed the same educational program in osteopathic techniques. Between manipulations, the practitioner returned to the specimen’s cervical neutral position. The current technique followed an osteopathic method outlined previously (Hartman, 1997) consisting in contacting the mastoid process with the intermediate phalanx of the medius (acting hand). The other hand gripped and stabilized the head heterolaterally. The practitioner applied a motion sequence of lateral bending, axial rotation to the opposite side and extension to reach the pre-manipulation position by focusing progressively on the intended segment. In this attitude, the impulse (thrust) is achieved by a fast rotation of the head with the acting hand. The side of the manipulation was randomly chosen for the three specimens. Note that for this technique, contact of the acting hand was not applied on C1 due to its poor accessibility and the presence of soft tissue. For this procedure, C2 was not the targeted segment and manipulation was considered applied to the entire UCS.

For all practitioners, UCS manipulation was achieved by combining right side bending and left rotation motions for one specimen and inversely (left side bending and right rotation motions) for two specimens. The entire procedure was performed on two separate days. Fig. 1 illustrates the experimental set-up and cluster location during manipulation procedure.

2.2. Medical imaging and 3D anatomical model

Prior to manipulation, computed tomography (CT) was performed (Siemens SOMATOM, helical mode, reconstruction: slice thickness = 1 mm, interslice spacing = 1 mm, image data format = DICOM 3.0) for each specimen including technical clusters. To obtain a 3D anatomical model of the bones of interest (C0 (skull), C1–C4 and thoracic segment), CT data were processed using a data segmentation procedure (Amira 3.0, Visage Imaging GmbH, Berlin, Germany). For providing anatomical motion representation and kinematics analysis, a registration method was performed using dedicated software (LhpFusionBox). The procedure for processing fusion of CT and motion data was reported previously (Van Sint Jan et al., 2002; Dugailly et al., 2011).

To express either regional or global kinematics in a conventional local anatomical frame (AF) (Wu et al., 2002), the reference system...
was defined for each bone of interest using anatomical landmarks; left and right transverse processes (TP), spinous process for vertebra, external occipital protuberance and mastoid processes (MP) for the skull, and lateral aspects of the manubrium and anterior medial part for the thorax segment. This procedure, defined as virtual palpation, allows reproducible identification of skeletal landmarks according detailed landmarks definitions (Van Sint Jan, 2007) to improve reliability of joint kinematics data (Van Sint Jan and Della Croce, 2005).

The TP or MP landmarks defined the z-axis. The orientation of x-axis was given as the normal axis to the z-axis through the corresponding posterior landmark, i.e. the spinous process or external occipital protuberance. The y-axis was given by the cross product of x and z. Then, the skull reference frame was set considering x-axis parallel to the Frankfurt plane. For the sternum, anatomical frame was defined using lateral (left–right) and anterior markers on the manubrium.

To agree with recommendations from the literature (Wu et al., 2002), anatomical frame (AF) conventions were respected, i.e. x, y and z-axes pointing forward, upward and to the right, respectively. Fig. 2 illustrates cervical anatomical modeling (Skull to C4 and Sternum) including local reference systems. The presence of morphological variations of cervical spine vertebra (e.g. spinous process orientation) may induce variations in AF orientation. For these reasons the center of the vertebral body may be more appropriate than the spinous process as proposed previously (Wu et al., 2002). However in the case of C3, the shape of the vertebral body does not allow proper definition of its center. In our small sample, the orientation of all cervical reference frames followed the conventions mentioned above.

2.3. Kinematics data collection and outcome measures

During the manipulation procedure, motion data was recorded using an optoelectronic system (Vicon® 612, 8 cameras, Oxford, United Kingdom; sampling freq: 200 Hz). Data were not filtered during and after processing.

The kinematic output was based on the mathematical techniques and method for computing angular displacement derived from helical axis data (Woltring, 1994). Motion was processed using the decomposition of helical axis rotation into helical angles around the axes of the coordinates system. This method was adapted to compute angular displacements (i.e. helical angles) in an anatomical reference system of interest (Cappozzo et al., 1995) for defining lateral bending movement (LB), axial rotation (AR) and flexion–extension around x, y and z-axis, respectively. The latter method was recently adapted for the upper cervical spine (Dugailly et al., 2010).

In the present study, global and regional kinematics data was processed for angular displacements achieved at the end of the impulse phase. Global and regional motion data were defined as angular displacements between C0 and the thorax (head–trunk) and between C0 and C2 (UCS) respectively.

2.4. Statistical analysis

Data analysis was performed to obtain descriptive statistics including means and standard deviations.

Inter- and intra-rater root mean square errors (RMS) were computed to measure regional and global kinematic reliability (within- and between sessions) at the end of the impulse phase.

3. Results

Analysis was performed on data obtained during manipulations for three specimens in one session (within-session data) and for two specimens on two separate days (between-session data). Average (3 repetitions by each of practitioners) kinematics outcomes (±SD) are reported in Table 1 for global and regional cervical kinematics for each specimen. In general, the average outcomes were almost comparable between practitioners whereas larger

Table 1

<table>
<thead>
<tr>
<th>Specimen 1</th>
<th>Practitioner 1</th>
<th>Practitioner 2</th>
<th>Practitioner 3</th>
<th>Specimen 2</th>
<th>Practitioner 1</th>
<th>Practitioner 2</th>
<th>Practitioner 3</th>
<th>Specimen 3</th>
<th>Practitioner 1</th>
<th>Practitioner 2</th>
<th>Practitioner 3</th>
</tr>
</thead>
</table>

474

Fig. 3. Head kinematics patterns relative to C2 during UCS manipulation (three trials) in left axial rotation, right side bending and extension for three practitioners. Angular displacements (in degrees) in lateral bending (x-axis, antero-posterior, green), axial rotation (y-axis, vertical, red) and flexion–extension (z-axis, transversal, blue). [For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.]
differences in motion magnitude were observed between specimen for some of the motion components. Table 2 shows reliability data of UCS manipulation in terms of root mean square errors (RMS). These data are represented for each motion component within and between sessions for each operator. Average data and inter-rater comparison between practitioners are reported as well.

Fig. 3 shows, for one specimen, angular displacement (raw data) curves of the head relative to C2 for three repetitions performed by the three practitioners. For each practitioner, impulse phase was clearly demonstrated for axial rotation component. Similar curve patterns were observed for each manipulation task with small differences among the practitioners. Note the similarity in magnitude for axial rotation and sagittal motion components for the three trials, and a slight increase of extension component during the third trial for the practitioner 1.

4. Discussion

This study is based on methods addressing analysis of global head—trunk kinematics during cervical spine manipulation using an optoelectronic system (Ngan et al., 2005; Dugailly et al., 2013). To assess regional motions, in vitro processing following a recently developed kinematics method for the UCS (Dugailly, 2011). The present results provide intra- and inter-rater reliability of global and regional 3D cervical kinematics during the UCS manipulation.

Average data agreed with recent in vivo global head—trunk kinematics results assessing cervical manipulation in sitting position (Dugailly et al., 2013). In contrast, other authors observed larger magnitude in axial rotation and flexion using a different manipulation procedure (Ngan et al., 2005). Furthermore, reduced axial rotation during cervical manipulation is likely to be related to the use of a specific manipulation technique based on the concept of multiple component technique (Hartman, 1997) aiming at minimizing range of motion and ensuring patient safety (Klein et al., 2003; Salem and Klein, 2013). Concerning the UCS, the average displacements were quite close to global head motion suggesting focus of motion components on target levels during the task. This observation was already mentioned in a previous study reporting lack of kinematics difference according to the cervical level of manipulation (Klein et al., 2003). Magnitude of UCS displacements was comparable to previous reported data for pre-manipulation positioning (Salem and Klein, 2013) or for upper spine mobilization (Cattrysse et al., 2007b). Note that for these studies displacements during impulse phase were not considered as opposed to the present outcomes. Usually, impulse amplitude has been measured to range from 6° to 13° for global head—trunk axial rotation during lower cervical spine manipulation (Triano and Schultz, 1994; Ngan et al., 2005; Dugailly et al., 2013). Moreover, minimal impulse magnitude is likely to be dependent on the manipulation technique (Williams and Cuesta-Vargas, 2012).

Concerning global head—trunk kinematics, a good between-sessions reliability have been estimated during manipulation of the lower cervical spine for pre-manipulation position, with ICC ranging from 0.73 to 0.84 (according to the motion component of interest) (Ngan et al., 2005). However, inter-rater reliability was found to be fair. Similar results have been observed for UCS mobilization (Cattrysse et al., 2010). In contrast to the latter, the present analysis addressed reliability of head—trunk and UCS 3D kinematics during UCS manipulation demonstrating low variations of angular displacement components. Each practitioner showed consistent kinematics patterns during repetitive manipulation tasks. These results provide consistency of 3D motion data with maximal average angular variations up to 2° and up to 4° for the within and between session, respectively. These values ranged from 3° to 6° between practitioners dependent on the motion component. The manual approach is expected to be dependent on practitioner skills, training and experience. Thus, variations between practitioners in terms of applied 3D kinematics may occur, especially when using multiple component approaches. These results suggest that regional focalization may be achieved using various kinematic patterns (Fig. 3). Awareness of the limits of these variations could be useful in pedagogical settings, especially kinematics feedback can be provided to the learner (Descarreaux et al., 2006).

To our best knowledge, very few studies have been examined the global or regional 3D kinematics during continuous motion tracking during UCS manipulation (Cattrysse et al., 2005). The latter reported that UCS manipulation corresponded to a 3D motion task for pre-manipulation positioning while an additional motion component occurred mainly in axial rotation during the impulse phase. Nevertheless, inter- and intra-rater reliability analysis was not reported in this previous work. The paucity of this kind of study is probably related to the lack of appropriate techniques allowing in vivo intervertebral motion assessment and imaging with sufficient accuracy and data acquisition frequency.

Our findings emphasize the low magnitude of motion components (as compared to known maximal motion ranges) especially considering axial rotation, often reported as an extrinsic risk factor for potential vascular complications after cervical manipulation (Hufnagel et al., 1999). Thus, although further research is needed in this field, it could be hypothesized that the use of a multi-component procedure could be recommended in clinical practice for minimizing displacements during UCS manipulation.

On the other hand, numerous risk factors, other than magnitude of cervical axial rotation, may contribute to vertebral artery dissection and stroke such as hypertension, environmental and genetic factors (Debette and Leys, 2009).

In addition, this new approach combines anatomical representation of motion during manipulation tasks using kinematics and imaging data fusion processing as previously described for several joint complexes (Dugailly et al., 2010). In our opinion, this method also comprises educational relevance for teaching spinal manipulative skills as compared to classical description based on contact, motion sequence and direction. The latter consideration has been underlined previously regarding visual feedback methods, facilitating both understanding and integrating technical skills during learning (Descarreaux et al., 2006).

Furthermore, assessing the reliability of manual tasks may be an option for controlling quality or agreement of technical skills during manipulative procedures practice.

Several limitations to this study may be mentioned. The experimentation was limited to three fresh cadavers, and considerations particularly relevant in case of age-related degenerative disorders were not taken into account, especially as differences in applied force between anatomical specimens and living subjects were mentioned (Symons et al., 2012). Variations between specimens are linked to our small sample, but might also reflect variability found in clinical practice (inter-individual variations in terms of stiffness, muscle tone and joint dysfunction).

Additionally, effect of cavitation phenomenon on kinematics was not investigated here. Nevertheless, no consensus exists in the literature considering this feature. Also, in vitro analysis may not be fully comparable to in vivo conditions even if muscular and articular anatomical structures were preserved during dissection and experimental setting. Finally, UCS was analyzed as one single functional unit C0–C2, and segmental kinematics (C0–C1 and C1–C2) was not reported while unintended motion components...
may occur at these levels during manipulation. Thus, further investigations are needed to analyze reliability of segmental kinematics including appraisals of the pre-manipulation positioning and the thrust phase.

5. Conclusion

This study emphasizes the feasibility of a protocol for analyzing kinematics of upper cervical spine manipulation and represents a starting point for assessing kinematics behaviors of different spinal manual techniques.

This study represents an innovative method that allows in vitro analysis of 3D kinematics reliability during UCS manipulation using anatomical modeling and motion representation. Also, such a method promotes perspectives in the educational field of manipulative procedures using data processing providing advanced visualization of global and segmental motion.

The small range of axial rotation highlights the consideration of HVLA manipulation using multi-component techniques for minimizing clinical risks and side effects.

Conflict of interest

The authors declare that they have no conflict of interest.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.math.2014.04.017.

References


