CAN PARAMETERS OF THE HELICAL AXIS BE MEASURED RELIABLY DURING ACTIVE CERVICAL MOVEMENTS?

ABSTRACT

Convex hull area (CHA) and mean angle (MA) have been proposed to describe the behaviour of the helical axis during joint kinematics. This study investigates the intra- and inter- session reliability of CHA and MA during active movements of the cervical spine. Twenty-seven healthy volunteers (19 women) aged 23±2.8 years participated. Each volunteer was tested on two sessions. All participants were instructed to perform the following active movements of the cervical spine: rotation, flexion/extension and lateral bending, each performed to full range and repeated ten consecutive times. Cervical movements were registered with an electromagnetic tracking system. For each participant, each movement and each session, range of motion (ROM), CHA and MA were extracted. ROM showed high intra- and inter-session reliability during all cervical spine movements using this method. Overall, the intra- and inter-session reliability of the helical axis parameters varied depending on the movement direction and ranged from *fair* to *almost perfect*. The intra- and inter-session reliability of CHA and MA were *almost perfect* during rotation whereas the intra- and inter-session reliability of CHA was *substantial* during lateral bending and intra- and inter-session reliability of MA ranged from *fair* to *substantial* during flexion/extension and lateral bending. This is the first study to evaluate the reliability of helical axis measures during active movements of the cervical spine. The results show that CHA and MA are promising descriptors of cervical kinematics which could be applied in future studies to evaluate neck function in patients with cervical spine disorders.

Keywords: Helical axis, cervical kinematics, reliability

INTRODUCTION

Movement analysis is commonly performed to evaluate the functional status of the cervical spine (Prushansky and Dvir, 2008). Besides traditionally used measures of joint kinematics, such as absolute range of main and coupled motion (ROM), other kinematic parameters have been considered. For example, a “Jerk index” has been used to describe the smoothness of cervical spine movement (Sjolander et al. , 2008) and the repositioning acuity has been evaluated to assess proprioception of the neck. Since joint movements predominantly involve rotation of one body segment relative to another, the helical axis (HA) of motion has been proposed as a promising approach to investigate three-dimensional joint kinematics. This approach considers rotations covering all six degrees of freedom but does not depend on any predefined coordinate system (Woltring et al. , 1985). Thus, HA defines a movement of a rigid body by reducing it into a rotation about and translation along a single axis (Cripton et al. , 2001). The HA location can be computed for any portion of movement defined by a given start and end position. In addition, the behaviour of the HA and its position within the ROM can be estimated by studying joint movement with small motion increments.

Previous investigations, including those on various human joints, showed that HAs are almost never exactly perpendicular to a cardinal plane and they are not fixed in space. Their position and orientation change substantially through the range (Graf and Stefanyshyn, 2012, Grip and Hager, 2013, Woltring et al. , 1994). The behaviour of the HA during motion depends on the irregularity of the joint surface but may also be influenced by motor control (Grip et al. , 2008). Since the HA analysis can reveal the quality of neck movement, a subject-specific analysis of HA motion may provide a more thorough understanding of the way a person moves and may be used to detect movement abnormalities in patients with neck disorders. This motion analysis can improve the standard clinical procedures of range of motion measurements or visual inspection of active movements.

We recently described two parameters to quantify the behaviour of the HA during active movement of the cervical spine. The convex hull area (CHA) and the mean angle (MA) were proposed to describe the HA position and orientation (Cescon et al. , 2014). Although these parameters have been suggested for the assessment of people with spinal conditions, the reliability of these measures have not yet been established (Grip et al. , 2007, Grip et al. , 2008, Woltring et al. , 1994). Thus, the aim of this study was to investigate the intra- and inter-session reliability of two HA parameters, the CHA and MA, during active movements of the cervical spine in healthy volunteers.

METHODS

Experimental sessions were conducted between April-June 2015 at the University of Applied Sciences and Arts of Southern Switzerland. The study was approved from the local ethics committee (CE 2291) and participants provided written informed consents.

Participants

Twenty-seven healthy volunteers (19 women, age: 23±2.8 years, BMI: 22.2±2.5 kg/m^2) participated. Inclusion criteria were: age between 20 and 30 years, pain-free movements of the neck, negative history for neck and shoulder pain in the last three months. Exclusion criteria were: positive history for neurological, rheumatic conditions or psychiatric disorders, whiplash in the previous six months, any cervical spine surgery.

Equipment

Active movements of the head were measured with an electromagnetic tracking system (G4, Polhemus Inc, USA). The sensor was fixed to the forehead with an adjustable helmet. Position (x,y,z) and orientation (pitch, roll, yaw) of the head with respect to the antenna were recorded at a sampling frequency of 120 Hz.

Procedures

Each volunteer was tested in two different sessions, three to five days apart. At the beginning of each session, the helmet was positioned on the head of the participant with the sensor aligned to the bridge of the nose, by a single operator (Fig.1). Subsequently, participants were seated on a wooden chair in an upright position with their head in a neutral position. The antenna was located on a wooden support at a height of 120 cm, approximately 40 cm from the participant's forehead.

All participants were instructed to perform the following active movements of the cervical spine: axial rotation, flexion/extension and lateral bending. Each single movement was executed reaching full range and repeated 10 times, which constituted a movement cycle. Movement cycles were performed at a natural speed. The participants were instructed to maintain contact between their spine and the back of the wooden chair, to avoid shoulder movements. First, each movement was performed a few times to familiarize the participants with the requested tasks. The order of the movement direction was randomized in each session by a computer-generated list. In the first session each movement cycle was performed twice in consecutive trials (trial 1 and 2), while in the second session each movement cycle was performed only once (trial 3) (Fig.1). The operator monitored the participants' position to ensure a consistent posture throughout the sessions.

Data processing

The HA of the head movements was computed with respect to the reference frame determined by the antenna. Angular intervals were set to 10 degrees in accordance with previous studies (Cescon, Cattrysse, 2014). The ROM was computed as the difference (in degrees) between the maximal flexion and maximal extension of the head or between maximum left and right rotation or lateral bending.

For each movement cycle, data from the first and the last repetitions were excluded in order to avoid possible artefacts or changes in angular velocity due to the beginning or the end of the series.

For the remaining 8 repetitions, the group of finite HAs were analysed with the minimum CHA technique (Fig.2) (Cescon et al 2014). The CHA is the area of the polygon that includes all the intersection points between the HA and a transversal plane. Small CHA values indicate that the joint is more stable, i.e. more similar to an ideal hinge. In addition, for each group of finite HA, the MA with respect to the mean axis (Fig.3) was extracted. The MA is the mean angle between each axis and their average. Small values indicate that the movement are more planar, thus an alternative way to indicate stability.

For each of the three movement cycles, we computed the ROM, and limited all the subsequent analysis to a sub-portion of the movement where the angle was within 95% of the smallest of the three ROMs. In this way we included data within the same range for each of the three movement cycles. For each participant, each movement cycle and each session the ROM, CHA and MA were extracted.

Statistical analysis

Descriptive statistics (mean and standard deviation) were used to describe ROM, CHA and MA.

To assess relative reliability, intra-class correlations (ICC) were computed (Shrout and Fleiss, 1979). ICC (2,k) was performed for both intra-session (trial 1 and trial 2) and inter-session reliability (trial 1 and trial 3). The criteria used for the interpretation of the ICCs were as follows: 0.00–0.19: *slight*; 0.20–0.39: *fair*; 0.40–0.59: *moderate*; 0.60–0.79: *substantial*; 0.80–1.00: *almost perfect* (Landis and Koch, 1977).

To assess absolute reliability, standard error of measurement (SEM) and minimal detectable change (MDC) were used. Statistical analysis was performed using SPSS Version 19.0 (SPSS Inc, Chicago, IL, USA). Significance was set to $\alpha=0.05$.

RESULTS

Twenty-seven healthy volunteers completed the first and the second session. Table 1 shows the mean value and standard deviation for each parameter during cervical active movements. The intra- and inter-session correlations, SEM, and MDC are also reported in Table 1. Overall, intra- and inter-session reliability were *almost perfect* for ROM (ICC ≥ 0.85). The intra- and inter-session reliability ranged from *moderate* to *almost perfect* for CHA with ICC values between 0.53 to 0.86, while for MA the ICC ranged from values between 0.38 to 0.95 indicating *fair* to *almost perfect* reliability. Specifically, the intra- and inter-session reliability for CHA and MA was *almost perfect* during rotation (ICC ≥ 0.80) and the intra- and inter-session reliability of CHA was *substantia*l during lateral bending (ICC ≥ 0.71). The intra-session reliability for CHA ranged from *substantial* to *almost perfect* during all movements with ICC values between 0.71 to 0.86. The intra- and inter-session reliability for MA ranged from *fair* to *substantial* during flexion/extension and lateral bending, with ICC values between 0.38 to 0.66.

DISCUSSION

This study is the first to quantify the reliability of CHA and MA measures during active movements of the cervical spine in healthy volunteers. The HA parameters were estimated using eight consecutive movements of the cervical spine. This was deemed necessary during the selected cervical spine movements since variability in the position and orientation of the cranio-cervical complex was expected. The CHA parameter (sensitive to the HA position) and MA parameter (sensitive to the HA orientation) were estimated using angle steps of 10 degrees. Previous investigations of the HA indicated that this angle step was an optimal compromise between the kinematic analysis resolution and the error in the HA estimation (Cescon et al. , 2015, Westphal et al. , 2013).

In accordance with previous studies, the intra- and inter-session reliability of measuring cervical ROM during the three movements was confirmed (Audette et al. , 2010, Fletcher and Bandy, 2008).

For the validity of the current reliability study focusing on HA parameters, consistency of ROM was required.

Intra- and inter-session reliability for CHA and MA measures were highest for rotation. The observed consistency also in the behaviour of HA parameters suggests that healthy participants, across different sessions, perform cervical rotation with essentially the same orientation and position of the cranio-cervical complex. This may be explained by fact that active cervical rotation is a relatively simple task. Most of the total range of motion during cervical rotation is permitted by the C1-C2 segment and the movement occurs around an axis passing perpendicular to the plane of the zygapophysial joints (Penning and Wilmink, 1987). This implies reduced changes in position of the cranio-cervical complex and predominately rotation in the horizontal plane. Conversely, intra- and inter-session reliability were not strongly supported for CHA and MA measures during flexion/extension and lateral bending. During flexion/extension, the cranio-cervical complex changes position in the sagittal plane and all cervical spine segments contribute to the total range of motion (Dvorak et al. , 1993, Lind et al. , 1989). Consequently, different motion patterns are likely during flexion/extension which would explain the reduced reliability for the HA parameters.

Considering the SEM of the HA parameters during the three movement cycles, it should be noted that its values were always lower than the standard deviations of the HA parameters suggesting a good response stability (i.e. the measurement errors do not exceed the variability). Moreover, the reported MDCs of the HA parameters indicate for the first time, thatthe expected amount of change is not related to the measurement error (i.e. a possible change in the subject's condition).

Some methodological considerations of this study include measurements only on asymptomatic and young participants and it is acknowledged that the results may differ in older adults or people with spinal conditions. Moreover, the electromagnetic device used for motion capture is prone to field distortions and results could be slightly different using optoelectronic systems (Cescon et al., 2015).

The angular velocity of the movements was not standardized and this may affect the reliability of HA measures.

In conclusion, by measuring the HA during active cervical movements we were able to demonstrate that CHA and MA are promising descriptors of cervical kinematics but their reliability is movement direction dependent. The intra- and inter-session reliability of CHA and MA was *almost perfect* during active cervical rotation suggesting the potential usefulness of these parameters to evaluate changes in cervical kinematics over time, for instance, following interventions in people with cervical spine disorders.

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CAPTIONS

Table 1. Intra- and inter-session reliability of ROM, CHA and MA measured during active movements of the cervical spine: rotation, flexion-extension and lateral bending. Abbreviations: ROM, range of motion; CHA, convex hull are; MA, mean angle.

Figure 1. A) Representation of the position of the sensor on the forehead and three movements performed by the participants. B) Graphical representation of the series of 10 movements performed by the participants. The sinusoids represent the Euler angle of the head with respect to the neutral position (red: rotation or “yaw”, green: lateral bending or “roll”, blue: flexion-extension or “pitch”).

Figure 2. A) Representation of the CHA during active movements of the cervical spine (red: rotation, green: lateral bending, blue: flexion-extension). The squares represent the intersection planes perpendicular to the mean axis. B) Representation of the extraction of the minimum CHA for the intersection points of the CHA with the corresponding plane. Abbreviations: CHA, convex hull are.

Figure 3. A) Representation of the HAs during the three active movements of the cervical spine (red: rotation, green: lateral bending, blue: flexion-extension). The HAs are translated in order to intersect each other in the origin. B) Representation of the extraction of the MA with respect to the mean axis for each movement. Abbreviations: HA, helical axis; MA, mean angle.