# Measurement of three-dimensional cervical segmental kinematics: Reliability of whole vertebrae and facet-based approaches

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**Title:** Measurement of three-dimensional cervical segmental kinematics: Reliability of two approaches

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## ABSTRACT

**Background:** Previous studies have used orientation and translation of whole-vertebrae to describe three-dimensional cervical segmental kinematics. Describing kinematics using facet joint movement may be more relevant to pathology and effects of interventions but has not been investigated in the cervical spine. This study compared the reliability of two different methods (whole-vertebrae vs facet joint) to evaluate cervical kinematics.

**Methods:** Two healthy adults each had six cervical (C1 to T1) magnetic resonance imaging scans, two each in neutral and left and right rotation. A semi-automated method of segmentation and alignment determined the relative orientation and translation of each whole-vertebrae and translation of each facet joint. Intra-rater and inter-rater reliability was determined using limits of agreement (LOA) with 95% confidence intervals and intraclass correlation coefficients ($ICC_{3,1}$ for intra- and $ICC_{2,1}$ for inter-rater).

**Results:** The LOA for intra-rater evaluation of facet movement was superior to whole vertebra translation. Both methods showed excellent intra-rater $ICC_{3,1}$ (0.80 to 0.99) and inter-rater $ICC_{2,1}$ (0.79 to 0.85) for all variables except for Euler angle for flexion/extension which was good (0.65). Intra-and inter-rater ICCs were better for facet movement than all measures of whole of vertebrae movement except Euler angles of axial rotation where no difference was detected.

**Conclusions:** Measurement of three-dimensional segmental kinematics using either the facet joint or the whole-vertebrae method demonstrated excellent and comparable reliability. These findings support the use of the facet joint method as an option for describing and investigating cervical segmental kinematics.

**Keywords:** facet joint, segmentation, movement analysis, biomechanics

## INTRODUCTION

A greater understanding of cervical segmental kinematics may be useful for describing the effects of pathology, movement and mechanisms underpinning the effectiveness of interventions such as manual therapy. Previous studies of three-dimensional (3D) cervical kinematics have considered segmental movement of each vertebra as having up to six degrees of freedom (three angles and three translations).[1-5] Other authors consider quantification of facet joint movement to be more useful in understanding segmental kinematics, but this approach has only been described for the lumbar spine.[6] To date, no investigation has described cervical segmental kinematics using facets as the reference point nor evaluated the reliability of this method. Thus, the aim of the present study was to evaluate intra- and inter-rater reliability of using facet joint movement to describe cervical segmental kinematics and compare this method to the reliability of using vertebral movement.

## METHODS

***Participants.*** Two healthy adults (1 male, 62 yrs; 1 female 40 yrs) volunteered for the study. Participants had no history of trauma in the previous 12 months, history of spinal surgery nor had any contraindications to magnetic resonance imaging (MRI) such as metal implants or claustrophobia. Informed consent was obtained prior to data collection and the study was approved by the university's Human Research Ethics Committee (PES/34/11/HREC).

***Procedures.*** Participants attended one testing session where they each had MRI scans of their neck in neutral and in full active right and left cervical rotation. The scans were repeated 30 minutes later for a total of six scans for each participant. Scans were performed with the participant supine and their head on a flat surface at a comfortable height. To ensure consistent positioning, with the participant in a neutral position, a sheet of acrylic was secured in the sagittal plane next to the left side of the participant's head. The participant kept their occiput in contact with the acrylic sheet during rotation to the right. The acrylic sheet was placed on the right side of the participant's head for left rotation. Images were acquired so all levels from C1 through T1 were visible. Thus, there were two participants, three positions, and eight vertebrae (seven motion segments) for a total of 96 vertebrae (72 motion segments) for intra- and inter-rater comparisons.

*Imaging acquisition.* MRI was performed using a 3-T scanner (Ingenia, Philips Medical Systems, Best, The Netherlands) using a neck coil with field of view of 25 cm, an acquisition matrix of 256 x 256 giving a voxel size of 1mm isotropic, and a reconstructed matrix of 512 x 512 to display a voxel size of 0.5mm isotropic. A 3D magnetization prepared T1 gradient echo sequence was used with a 1 mm slice thickness and no interslice gap.

*Image processing.* Processing was performed in Mimics V17.9 and 3Matic V9 (Materialise NV). 3D vertebral contours of each vertebra were constructed using a semi-automatic procedure similar to that described by Ishii et al.[7] The procedure involved manually tracing the vertebra's contours on approximately one third of the sagittal slices for each vertebra. The software was used to interpolate the contours to include all slices. Manual corrections were made in all three planes. Automated functions within the software were then used to construct and smooth a 3D contour of each vertebra. Three points were defined on each vertebral contour. The centre of gravity of the whole contour (COG) was calculated using an automated function in the software. The centre of each inferior facet (COF) was determined by manually drawing an outline of each facet and using the software to calculate the centre of the surface of each facet (COF).

Reliability of position compared repeated analysis of the location and orientation of each vertebra separately in neutral and rotated positions when performed by the same (intra-) or different (inter-) raters. Figure 1 shows an example of repeated processing of one cervical vertebra from the same MRI. An automated voxel-based registration using 3Matic was used to align contours 1) between repeated segmentation of the same vertebra from the same scan and 2) between the same vertebrae in neutral and rotated positions. Euler angles were calculated using the order Flex/Ext (X), Lateral Flexion (Y), Rotation (Z).[8]

### *Raters*

Two raters experienced in using the software performed all image processing. For intra-rater reliability, the two repeated measures were separated by a minimum of 1-week.

### Data analysis

Reliability was calculated for 1) whole-vertebrae measures including orientation and translation; and 2) facet joint measures of translation only. For position, the measures were calculated from repeated analysis of each vertebra in each scan (Figure 1). For movement, measures were calculated from pairs of scans (one neutral and the other rotated) as the change in position from neutral to rotated positions for each vertebra or facet in relation to the level below (Figure 2). Reliability of position was therefore determined from repeated analysis of the same scan, while movement compared the same pair of scans.

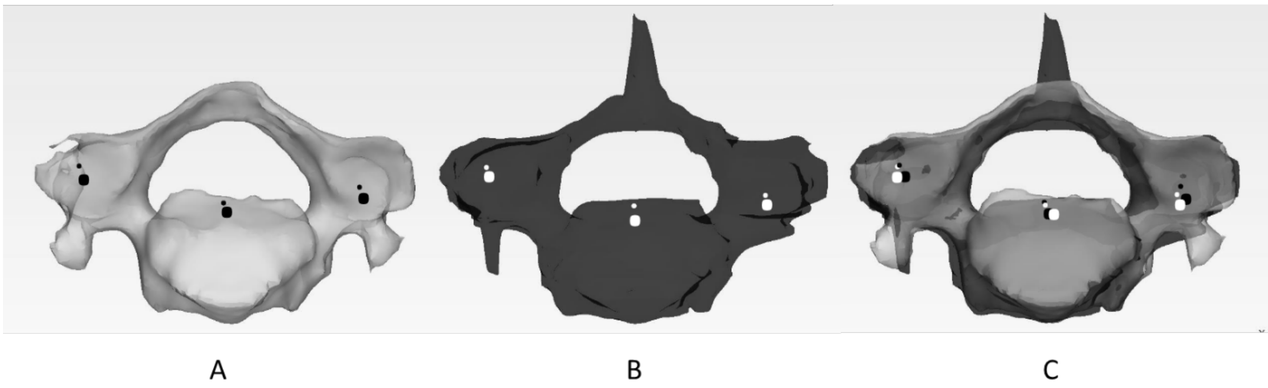


Figure 1. Example of image processing for inter-rater reliability of position. All three images show the inferior surface of C3 from the same MRI. Image A shows the contour from the analysis by one operator. The black dots indicate the location of the COG and of the two COFs. Image B shows the contour from the second operator with white dots indicating the COG and the COFs. Image C shows the two versions superimposed. The 3D distances between the COG from the two operators were calculated by the software. The agreement in orientation was calculated as the Euler angles of the change in orientation that occurred when the contour from the second operator was aligned with that from first operators using an automated voxel-based approach.

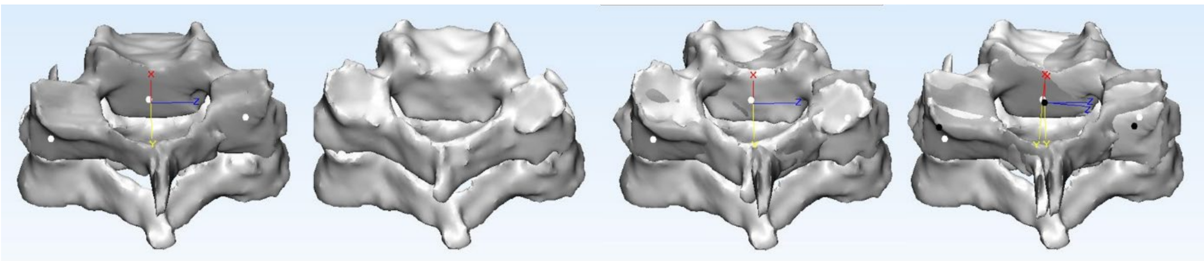


Figure 2. Example of image processing for calculation of segmental movement between C3 and C4. Image A shows contours of C3 and C4 in neutral with the inertial axes, COG and COF. Image B shows C3 and C4 in the rotated position. Image C shows the rotated C3 and C4 transposed so that the rotated C4 is aligned with the neutral C4. In Image D, a duplicate of C3 including the inertial axes, COG and COF (now black dots) have been aligned with the rotated C3. The distances between the COG and COF and the Euler angles between the inertial axes quantify the movement at C3 from the neutral to rotated positions. Note that aligning the neutral C3 with the rotated C3 rather than defining the axes and points independently on the rotated C3 eliminates a potential source of error that could result from redefining these elements on a contour of the rotated C3.

Statistics for movement and position included bias and 95% limits of agreement (LOA) with 95% confidence intervals (CIs).[9] Variables were combined for further analysis if no differences in the variability were found. Violin plots were constructed for data visualisation to provide a data-rich visual representation of agreement.[10] Intra-rater and inter-rater reliability was determined using intraclass correlation coefficients $ICC_{3,1}$ and $ICC_{2,1}$ respectively.[11] ICCs $< 0.40$ were considered to indicate poor, 0.40–0.75 fair to good, and $> 0.75$ excellent reliability.[12] For each ICC, 95% CIs were generated. Non-overlap of CIs for LOAs or ICCs were considered to indicate significant differences in variability. Statistical analysis was performed with SPSS statistical software (Version 22, SPSS Inc., Chicago, IL).

## RESULTS

No differences were found between intra- or inter-rater ICCs or LOAs by (i) level for Euler angles, COG or COF; (ii) axis for COG or COF; or (iii) side for COF. Therefore, one intra- and inter-rater LOA was utilised for COG, COF, and each axis of Euler angles (Figures 3 and 4). One ICC was calculated for each axis and one each for COG and COF.

*Position*.

The LOAs were significantly smaller for intra-rater reliability than for inter-rater reliability for COF and for each axis of Euler angles, but were not significantly different for COG. The intra-rater LOAs were smaller for COF than COG, but the inter-rater LOAs were larger for COF than COG. In other words, the two raters had greater variation in outlining facets than in defining whole vertebra contours.

*Movement*. There were no differences in LOAs for orientation, COG or COF by direction or level. Therefore, a single LOA was calculated for intra- and inter-rater reliability for each variable. The intra- and inter-rater LOAs for movement between the neutral and rotated positions as Euler angles for each axis are shown in Figure 3. The LOAs for COG and COF are shown in Figure 4.

Intra-rater LOAs were smaller than inter-rater LOAs for each axis of Euler angles, but did not reach statistical significance. Intra-rater LOAs were significantly smaller than intra-rater LOAs for COG and COF.

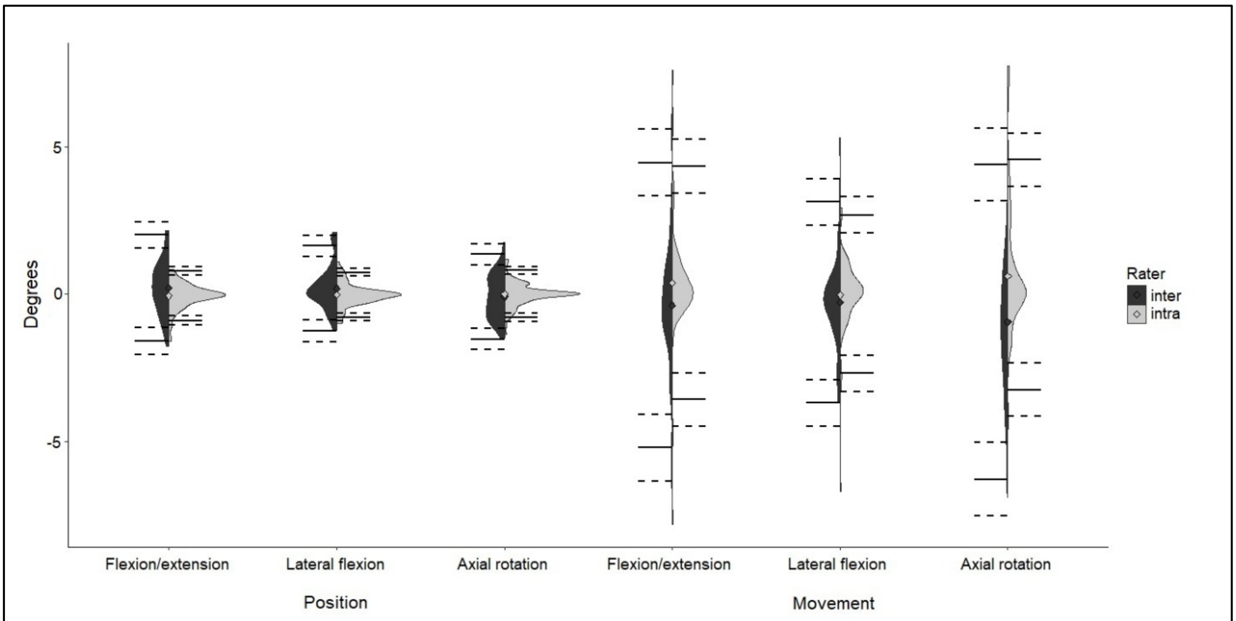

Figure 3. Data distribution of the differences in Euler angles for position and movement. Intra- and inter-rater 95% LOA are shown as solid lines and their 95% confidence intervals as dashed lines.

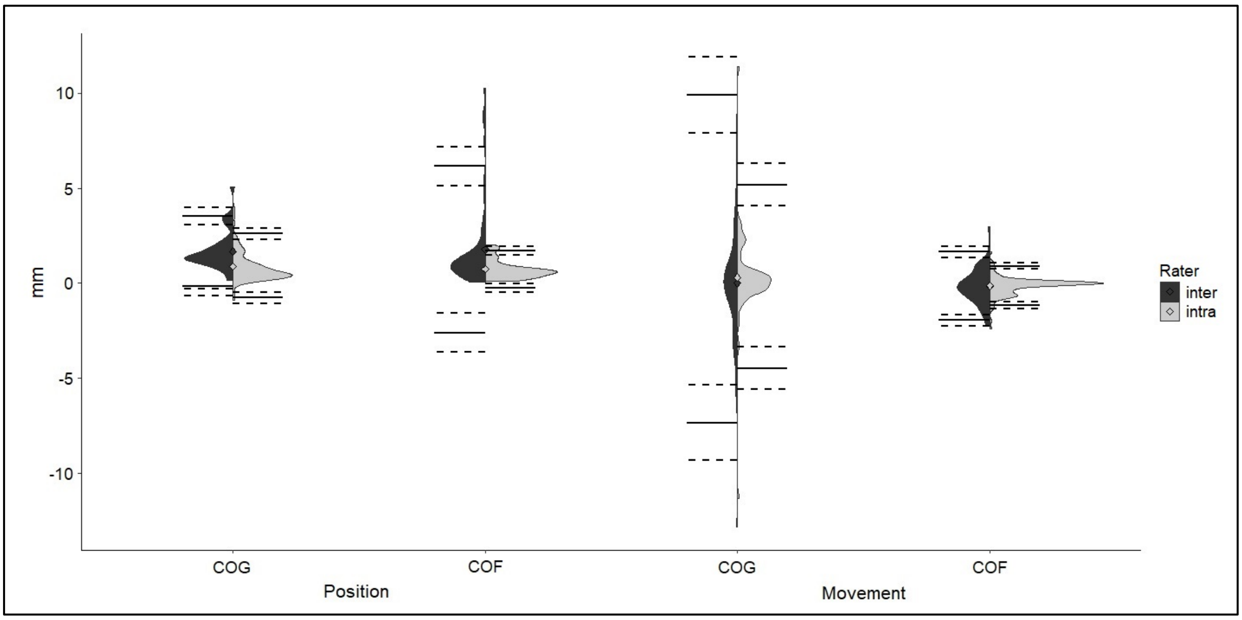


Figure 4. Data distribution of the differences in COG and COF for position and movement. Intra- and inter-rater 95% LOA are shown as solid lines and their 95% confidence intervals as dashed lines.

The ICCs for intra- and inter-rater reliability (Table 1) were all excellent (>0.75), except for Euler angles in flexion/extension which was considered good.[12] The ICC values for intra-rater reliability were consistently higher than those for inter-rater reliability for all comparisons but only reached significance for facet translation and Euler angle of axial rotation.

The reliability of COF measures were generally superior to the reliability of whole-vertebra measures as indicated by both the intra- and inter-rater ICCs for COF being higher than the ICCs of all of the whole-vertebra measures except for Euler angle in axial rotation. The intra-rater $ICC_{3,1}$ value for axial rotation was significantly greater than the values for the other axes. The intra- and inter-rater ICCs for COF were significantly greater than the corresponding ICCs for Euler angles (except for intra-rater axial rotation) and COGs.

## **DISCUSSION**

The aim of this study was to compare intra- and inter-rater reliability of two approaches of assessing position and segmental kinematics of the cervical spine: comparing whole-vertebra measures (Euler angles and COG) with movement of facets (COF). Reliability of using facets was superior to most whole-vertebrae measures. The ICCs showed excellent reliability for all measures except Euler angles for flexion/extension which were good. The smaller ICC for orientation in flexion/extension is likely due to smaller movements around this axis during the physiological movement of axial rotation that was evaluated in this study.

From a measurement perspective, the COF approach would appear to be at least as reliable as the traditional whole-vertebra approach for evaluating kinematics in the cervical spine. It has been argued that quantification of facet joint kinematics is important for improved understanding of normal mechanics, the consequences of pathology, and the effect of targeted interventions.[6,13] While Byrne et al[6] quantified *in vivo* lumbar facet joint motion, to our knowledge, the present study is the first to have described a method for measuring cervical segmental kinematics using facets as the reference point. The results support utilising the facet joint method to describe cervical kinematics in future studies investigating cervical spine pathology and the effect of interventions.

A practical application of the findings of this study would be in the extent to which these methods are able to detect changes in segmental kinematics following an intervention such as surgery, cervical joint mobilizations or local facet joint injections. For example, intra-rater LOAs of Euler angles in axial rotation and COFs between neutral and rotated positions were both approximately one third of the mean values for each variable. That is, either the Euler angle or COF approach would be expected to be able to detect differences in movement in a given individual of greater than one third of the average movement.

One potential difficulty with the COF approach is that the outlines of the facets showed considerable variability between raters probably resulting from the outlines having been drawn manually. The specific point that is selected on the facets, however does not appear to be critical since the inter-rater ICCs for COF movement were not only better than the ICCs for COF position, but also better than most whole-vertebra measures.

Segmental kinematics in the cervical spine have been investigated utilising different imaging acquisition methods such as MRI (as used in this study),[1-3] computed tomography (CT),[3] x-ray imaging,[14,15] and fluoroscopy.[4,5] Although reliability of MRI is somewhat worse than other methods (Table 2), MRI can be particularly useful when wanting to perform repeat scans, as may be the case pre- and post- an intervention, given there is no ionising radiation compared to the other aforementioned methods. Different methods have also been used for aligning or comparing the positions of vertebrae. To date, the majority of studies have evaluated segmental kinematics of the cervical spine by defining coordinate systems or points based on anatomical landmarks of individual vertebrae (Table 2). Our study suggests that defining points on separate images of a vertebra may introduce an additional source of error as compared with aligning contours directly as was done in the current study.

Strengths of the current study include it being an *in vivo* study using non-ionising imaging techniques. Although there were only two raters and two participants, positions of 96 vertebrae and movement of 72 motion segments were compared ensuring sufficient data for analysis. Whilst the available equipment resulted in the imaging being performed in supine, the reliability of the method would be expected to be independent of scan position.

## SUMMARY AND CONCLUSION

Characterising cervical segmental kinematics using translation of facet joints was at least as reliable as the more traditional approach of using whole of vertebra measures. The results of this study, combined with the idea that facet movement may be a clinically relevant measure, suggest that it would be reasonable to consider facet joint movement in future research investigating cervical segmental kinematics.

Table 1. Intraclass correlation coefficients (ICC) and 95% confidence intervals (CI) of intra- and inter-rater reliability for Euler angles, vertebra and facet translations.

| | | Flexion/extension (x) | Lateral flexion (y) | Axial rotation (z) | COG | COF |
|---|---|---|---|---|---|---|
| **Intra-rater reliability $ICC_{3,1}$** | **ICC** | 0.80* | 0.89* | 1.00 | 0.91* | 1.00 |
| | **95% CI** | 0.66-0.88 | 0.79-0.93 | 0.99-1.00 | 0.84-0.95 | 0.99-1.00 |
| **Inter-rater reliability $ICC_{2,1}$** | **ICC** | 0.65* | 0.85* | 0.85* | 0.79* | 0.98 |
| | **95% CI** | 0.41-0.80 | 0.73-0.91 | 0.74-0.91 | 0.63-0.88 | 0.98-0.99 |

* indicates significant differences between whole-vertebrae and COF ICCs

**Table 2**. Comparison reliability with previous studies.

| **Modality** | **Reliability** | **Comparable reliability from current study** |
|---|---|---|
| X ray[15] | LOA = 4° | LOA > 0.9 |
| Fluoroscopy[4] | LOA = 1.25° | LOA > 0.9 |
| MRI[2] *** | LOA = 0.8° | LOA > 0.9 |
| | | |
| Biplanar stereoradiography[16] | LOA = 2.6-3.3° | LOA = 3.1 to 4.5° |
| CT or MRI with dual fluoroscopy using image matching, lumbar spine[17] | LOA from CT images = 0.8 to 1.2°<br>LOA from MR images = 1.2 to 1.8° | LOA = 3.1 to 4.5° |
| CT with dual fluoroscopy, cervical spine[1] | LOA = 0.2 to 1.2° | LOA > 0.9 |
| CT[18] | | ICC = 0.80 to 0.99 |
| Fluoroscopy for time course of flexion/extension | LOA = 0.2° | LOA > 0.9 |

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