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Three-dimensional Cervical Movement Characteristics in Healthy Subjects and Subgroups of Chronic Neck Pain Patients Based on Their Pain Location

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Study Design. A cross-sectional observational study of three-dimensional (3D) cervical kinematics in 41 chronic neck pain (CNPs) patients and 156 asymptomatic controls.

Objective. The objective was to investigate 3D cervical kinematics by analyzing and comparing quantitative and qualitative parameters in healthy subjects and CNPs. Furthermore, subgroups were formed to explore the influence of pain-location on cervical kinematics. The possible correlation of kinematic parameters with the degree of functional disability was examined as well.

Summary of Background Data. In patients with chronic neck pain, a clear pathological cause is frequently not identifiable. Therefore, the need to assess neck pain with a broader view than structure or anatomical-based divergences is desirable.

Methods. Movements of the cervical spine were registered using an electromagnetic tracking system. Quantitative and qualitative kinematics were analyzed for active axial rotation, lateral bending, and flexion-extension motion components.

Results. During lateral bending, the range of the main motion demonstrated significant higher values ($P = 0.001$) in the controls (mean: $68.67^\circ \pm 15.17^\circ$) than patients (mean: $59.28^\circ \pm 15.41^\circ$). Significant differences were demonstrated between subgroups for several kinematic parameters ($P < 0.05$). Although differences were predominantly recorded between the ''symmetrical'' and ''asymmetrical'' pain group, some parameters also distinguished subgroups from controls. On average, the symmetrical group showed significant less harmonic movement patterns, expressed by qualitative parameters, in comparison with the ''asymmetrical'' group and controls. Furthermore, the ''asymmetrical'' group showed significant lower scores on quantitative parameters than the ''symmetrical'' group and controls. The degree of functional disability correlated moderately with changes in qualitative parameters.

Conclusion. In this study, chronic neck pain patients with a symmetrical pain pattern showed significant poorer quality of movement, while those with asymmetrical pain showed a significant reduction in quantitative measures. Subgrouping of neck patients based on pain location may be of help for further research and clinics.

Key words: cervical spine, kinematics, neck pain, pain location, qualitative parameters, quantitative parameters, subgrouping.

Level of evidence: 4

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The need to assess neck pain with a broader view than structure or anatomical-based divergences is desirable.[1] Therefore, further research and clinical development are needed to approach a unifying model of diagnoses and subgroup definitions.[2]

Numerous studies on cervical kinematics have focused on the range-of-motion (ROM) as the main parameter.[3–16] Furthermore, the need for a normative database with kinematic parameters for cervical movements has been advocated.[4,15] Unfortunately, there is no consensus in the literature as to which parameters can best be used.

The data on cervical ROM (CROM) in different pathologies are inconclusive and contradictory. Although Woodhouse and Vasselijn[12] found that the decrease in the CROM in patients with whiplash-associated disorders (WAD) differs significantly from the decrease in patients with idiopathic chronic neck-pain (CNP), Sjölander *et al.*[11] did not find that difference.[13,14] Bergman *et al.* found a vast variability in CROM in healthy subjects as well as in patients with neck and shoulder complaints. This leads to the question whether ROM should be used as a diagnostic or evaluative parameter.[6,16,17] The value of the coupling of motion, which occurs in the cervical spine, as a kinematic parameter is discussed as well.[12,15,18] Beside the previously mentioned focus on quantitative aspects of kinematics, others have focused on qualitative kinematic parameters.[11,19–21] Sjölander *et al.*[11] used the jerk index (the change in acceleration during a motion) to discriminate a control group from patients with WAD and CNP. Feipel *et al.*[19] found a difference in the root mean square of the raw data of a movement and the polynomial fit between patients with WAD and healthy controls. Cattrysse *et al.*[20] found a statistical significant difference in these two kinematic parameters between patients with an anterior cervical fusion and healthy subjects.

Therefore, pain location is considered to be an essential factor for diagnostic and therapeutic choices in patients with musculoskeletal pain.[22–25] However, little is known regarding the pain location in relation to cervical kinematic features.

The overall objective of this work was to obtain quantitative as well as qualitative kinematic data of the cervical spine in healthy subjects and to compare these parameters with data from patients with CNP and subgroups on the basis of their pain location. Furthermore, the relation between changes in cervical kinematics and the degree of disability as measured with the Neck Disability Index (NDI) was investigated as well.

The results of this study may be of interest for the development of new diagnostic and therapeutic strategies.

MATERIALS AND METHODS

Subjects

A group of 156 healthy controls and 41 patients with CNP with mean age 40.85 years and 45.72 years (±13.19 yrs; range: 21–65 yrs) (±14.3 yrs; range: 18–65 yrs) was selected. Subgroups were made on the basis of pain location, as marked on a body chart, and consisted of an "asymmetrical" (=left or right pain) ($n = 16$) and a "symmetrical" (both sides and central pain) ($n = 21$) pain group.

Patients were eligible if they were having nonspecific neck pain for at least 3 months. Exclusion criteria for the patient group were (1) neck complaints for less than 3 months; (2) neurological signs or symptoms; (3) trauma or surgery history of the cervical spine; (4) malignancy; (5) use of medication influencing muscle tension; and (6) presence of shoulder disorders. The ethics committee of the Brussels University Hospital (UZBrussel) approved the study and each participant signed informed consent before testing. Testing took place at one of the researchers' private manual therapy practices and at the Free Brussels University (VUB).

Materials

Registration of movements was executed with an electromagnetic tracking system (Flock of Birds; Ascension Technologies, Shelburne, VT). To avoid interference, all ferromagnetic material was banned from the testing area and subjects were seated on a wooden chair.[26] The transmitter was installed at sternum height in front of the subjects. A local reference frame for the head (Figure 1A) and the thorax (Figure 1B) was constructed before the two receivers were attached to the skull and the sternum.

Procedure

All subjects were asked to make three different active movements, not passive, over a maximal range of motion without causing discomfort. Each movement started and finished in neutral position and was executed three consecutive times. One set of movements consisted of (1) axial rotation (AR); (2) lateral bending (LB); and (3) flexion-extension (FE).

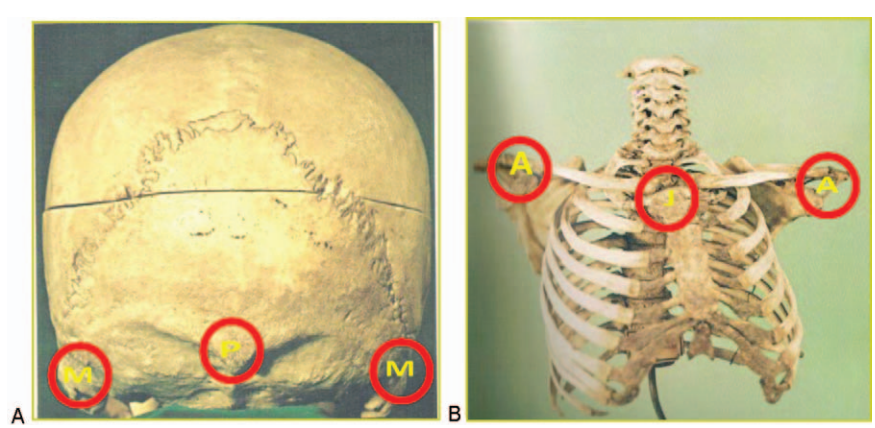

Figure 1. Bony landmarks for the reference frame. **A**, For the head: M = the most caudal point of the mastoideus process on the left, P = the most dorsal point of the external occipital protuberance; **B**, For the thorax: A = the most lateral point of the acromion on the left and right, J = the most caudal point of the jugular notch.

Each set was repeated three times to ensure enough interpretable data.

Patients were asked to fill out the NDI. Questionnaires and pain information were gathered after all measurements to avoid bias on the part of the patients and to keep the researchers blinded with respect to pain classification during the registration procedure.

Three manual therapists (experience between 2 and 20 yrs) were equally trained in the application of the measurement device and performed all measurements.

Data Collection

Position data and direction cosines were recorded using the winBIRD software (Shelburne, VT). The collected data were transformed in EXCEL worksheets in order to be analyzed by Mathcad 15 software (Needham, MA). The results were analyzed using SPSS19 (SPSS Inc., Armonk, New York). AR and LB were analyzed using the ZYX Euler sequence. FE was analyzed using the YZX sequence.

The following quantitative kinematic parameters were calculated: the ROM of the main and coupled motions; the cross-correlation (CC) between the main and coupled motion; the ratio = SD (AR)/ SD (LB).

The Euclidean norm representing global 3D motion = ($\sqrt{AR^2 + LB^2 + FE^2}$

The following qualitative kinematic parameters (measures of smoothness) were used: the standard error of measurement on the deviation of the original data and a sixth polynomial function (Figure 2A); and the jerk index (the root mean square of the jerk) (Figure 2B).

Statistical Analysis

Normality of data distribution was checked using the Kolmogorov-Smirnov test. Descriptive statistics were performed for gender, pain location, and motion coupling patterns. Differences between the control group and the CNP group were tested using the Student *t*-test. An analysis of variance (ANOVA) was performed to test for differences in kinematics due to pain location. Bonferroni correction was used for *posthoc* testing in ANOVA. To test for correlation between age and ROM and between kinematic parameters and NDI scores, Pearson correlation was used.

RESULTS

The demographic characteristics of the participants are described in Table 1. There was no significant difference between the groups regarding age and between the two groups of patients regarding scores on NDI. Patients showed a mild functional disability. Due to technical problems during the registrations, not all kinematic data could be analyzed; therefore, the number of subjects analyzed per motion component varies (150 controls for AR and 146 for LB and FE; 35 patients for FE and 36 for AR and LB).

Correlation With Age

Slight to fair correlations were found between age and quantitative parameters during AR and LB. The jerkiness of the main motion during LB showed slight correlation with age as well ($r = -0.278$, $P < 0.001$). Consequently, age was not taken into account as a covariant in the statistical analysis due to the low correlation values (Table 2).

Axial Rotation

Between subgroups, ANOVA demonstrated significant differences on several kinematic parameters. The "symmetrical" pain group showed substantially less harmonic motion patterns for the conjunct LB than the control group,

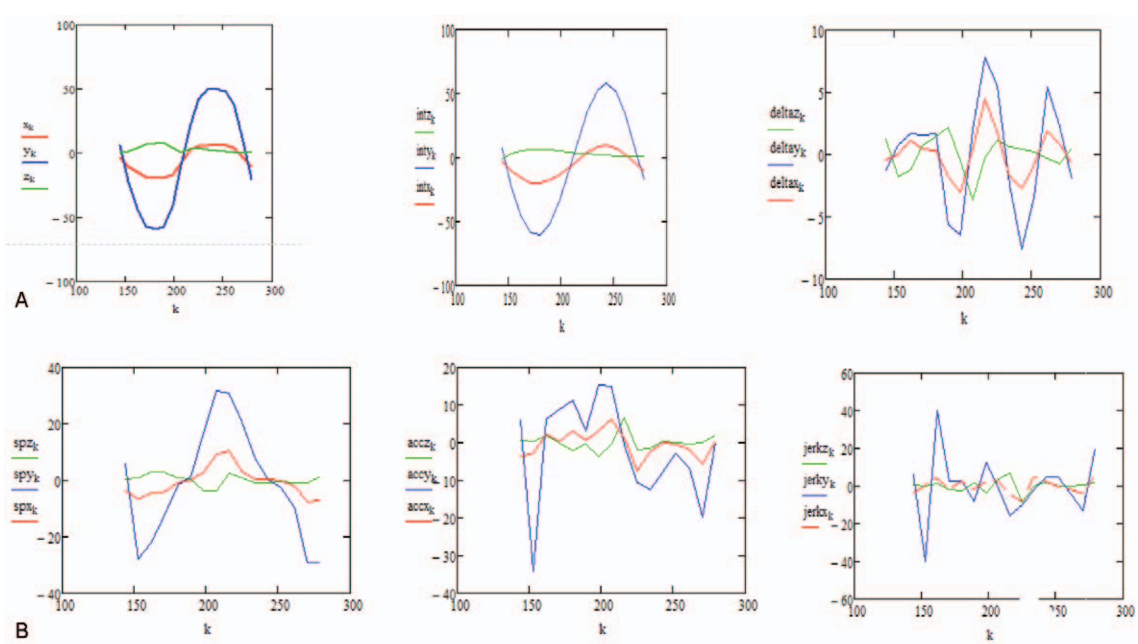

Figure 2. A, Original data and polynomial fit and their difference during rotation of a healthy subject. **B**, Speed, acceleration, and jerk data from the same subject.

TABLE 1. Demographic Characteristics of the Subjects

Characteristics	C ($n = 150$)	ASNP ($n = 16$)	SNP ($n = 21$)	P
Gender: M /F	91/59	5/11	4/17	>0.001*
Age (years)	40.85 (14.42)	49.40 (12.20)	43.10 (13.53)	0.078
NDI	–	22.80 (14.33)	17.14 (9.78)	0,168
Ipsi-coupling LB	131	16	15	
AR	99	8	12	
Contra-coupling LB	15	0	5	
AR	51	7	9	

Mean values and standard variations for age and NDI. The distribution of men and women in each group and ipsi- or contralateral coupling are given in number of persons. P values of between-group difference for age, gender, and NDI are indicated.

*Chi-square test.

AR indicates axial rotation; ASNP, asymmetrical neck pain; C, controls; LB, lateral bending; NDI, Neck Disability Index (range: 0–100); SNP, symmetrical neck pain.

expressed by the deviation from the polynomial fit (Figure 3A). *Post hoc* analysis showed a poorer quality of the conjunct movements in the "symmetrical" pain group and less ROM of the conjunct movements in the "asymmetrical" pain group (Figure 3A–C). In addition, the main AR component showed a jerkier pattern in the "symmetrical" pain group than the "asymmetrical" pain group (Figure 3B). The ratio between the AR and the LB components differed as well, with a higher ratio in the "asymmetrical" group (mean: 8.12; SD: ±5.73) than the "symmetrical" group (mean: 4.63; SD: ±2.43).

Lateral Bending

The Student *t*-test demonstrated significantly ($P = 0.001$) more LB mobility in the control group (mean: 68.67°; SD: ±15.17°) than the patients (mean: 59.28°; SD: ±15.41°). Furthermore, ANOVA pointed out differences between the subgroups for parameters related to the main LB component. *Posthoc* analysis demonstrated substantially less ROM of the primary LB in the "asymmetrical" pain group compared with the controls (Figure 4B). And a smoother movement pattern, indicated by the jerk-index, was presented in the "asymmetrical" group compared with the "symmetrical" pain group (Figure 4A). In addition, the cross-correlation showed a significant difference ($P = 0.047$) between controls (mean: 0.65; SD: ±0.45) and the "symmetrical" pain group (mean: 0.40; SD: ±0.46).

TABLE 2. Correlation Between Age and Kinematic Parameters Expressed by Pearson Correlation Coefficient

Age	AR	LB
ROM AR	0.160*	0.274†
ROM LB	NS	−0.396†
Ratio	NS	0.337†
Cross-correlation	NS	0.267†
Euclidean norm	0.172*	NS
Jerk on LB	NS	−0.278†

*Correlation is significant at the 0.05 level (2-tailed).

†Correlation is significant at the 0.01 level (2-tailed).

AR indicates axial rotation; LB, lateral bending; ROM, range of motion.

Flexion-extension

ANOVA revealed a significant difference between the subgroups for the jerk-index of the main FE motion. A smoother movement was registered for the main motion component in the "asymmetrical" group compared with the "symmetrical" group (Figure 5).

Coupling Patterns

During AR, 99 of 150 control subjects showed ipsilateral coupling (CC: 0.20; SD: ±0.52), whereas during LB, 131 of 146 control subjects demonstrated ipsilateral coupling (CC: 0.65; SD: ±0.45). The patient group showed ipsilateral coupling (CC: 0.10; SD: ±0.52) in 20 of 36 subjects during AR, whereas during LB, 31 of 36 subjects showed ipsilateral coupling (CC: 0.55; SD: ±0.42). Furthermore, within the experimental group, all subjects in the "asymmetrical" pain group demonstrated ipsilateral coupling patterns during LB (Table 1). Healthy subjects showed statistically more ipsilateral coupling ($P = 0.037$) patterns during LB (CC: 0.78; SD: ±0.21) than the patient group (CC: 0.69; SD: ±0.25).

Correlation With NDI

A fair-to-moderate relationship was demonstrated between the degree of impairment measured by the NDI and changes in cervical kinematics. Correlation was present for the jerkiness of the coupled FE during LB ($r = -0.383$; $P = 0.05$) and the jerkiness during FE for the main movement ($r = -0.41$; $P = 0.05$).

DISCUSSION

Controls showed more mobility for the main motion component of the respective movements (mean difference 9.39°), but this was only significant during active LB. So, a strict differentiation between the two groups merely on the grounds of ROM does not seem justified.

For all three planar motions, the jerk-index of the main motion component differed significantly between the "symmetrical" and "asymmetrical" pain group. During AR, the

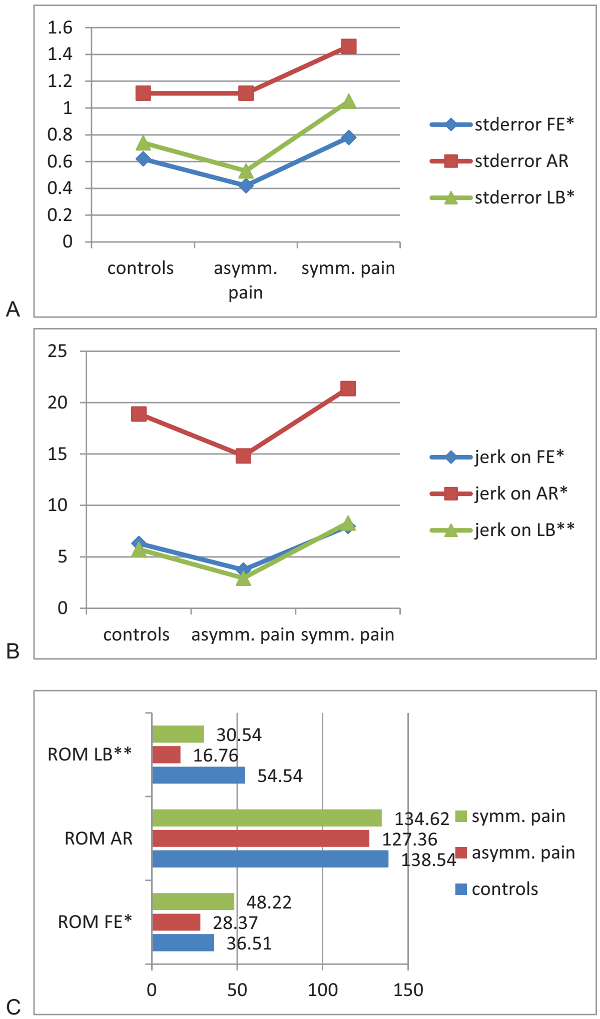

Figure 3. Cervical kinematics during active axial rotation comparing controls, asymmetrical pain group, and symmetrical pain group: **A**, Polynomial fit of the main and conjunct movements during axial rotation (smaller values indicate a smoother movement). **B**, Jerkiness of the main and conjunct movements during axial rotation (smaller values indicate a smoother movement). **C**, ROM of the main and conjunct movements during axial rotation. Significant differences between groups (ANOVA and Kruskal-Wallis test): $^{*}P<0.05$ and $^{**}P<0.01$. AR indicates active axial rotation; FE, active flexion-extension; LB, active lateral bending; Stderror, standard error between raw data and a sixth polynomial function.

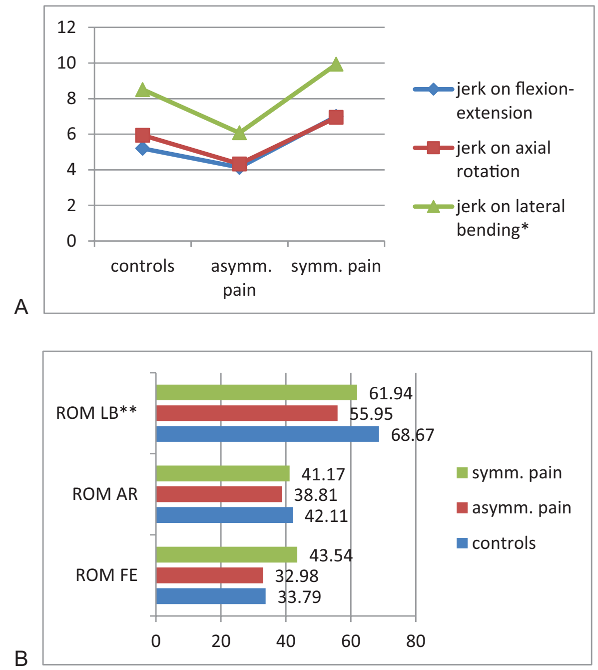

Figure 4. A, Jerkiness of the main and conjunct movements during lateral bending (smaller values indicate a more smoother movement). B, ROM of the main and conjunct movements during lateral bending. ANOVA and Kruskal-Wallis test: $^{*}P<0.05$ and $^{**}P<0.01$. AR indicates active axial rotation; FE, active flexion-extension; LB, active lateral bending.

ROM and the polynomial fit of the coupled movements differed significantly as well. Although not always statistically significant, it is noticeable that the "asymmetrical" pain group scores worse on quantitative parameters compared with the "symmetrical" group, whereas the higher values on qualitative parameters in the "symmetrical" group than the "asymmetrical" group indicate a less smooth movement pattern in the "symmetrical" group.

The correlation between NDI and kinematic parameters was moderate (ranging from −0.411 to −0.331). Although significant on the jerkiness of the FE component during planar LB and planar FE, the correlation is too weak to establish a direct relationship between kinematic changes and the degree of disability as measured by the NDI.

Differentiation Between CNPs and Controls

The present results showed a significant difference in the LB component during primary LB, whereas Cagnie *et al.*[8] merely found significant differences in the ROM during AR. The present results are in agreement with the results of Sjölander *et al.*[11] who found a reduction in primary AR ROM that was not statistically significant. Whereas others found a significant reduction in conjunct movements

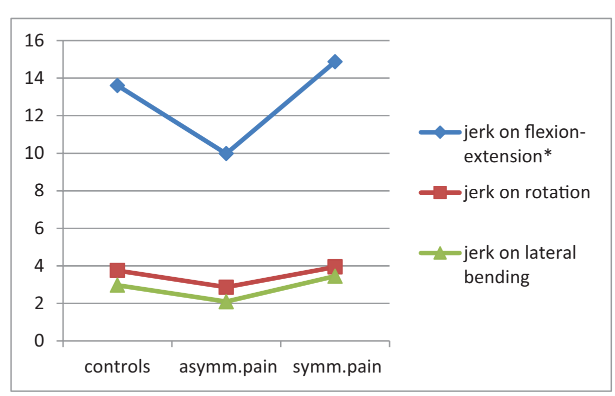

Figure 5. Jerkiness of the main and conjunct movements during flexion-extension (smaller values indicate a smoother movement). $^{*}P<0.05$.

especially during primary AR,[12] the decrease in conjunct movements during AR in CNPs in the present study was not statistically significant. These differences may partially be explained by methodological differences as discussed later.

Differences in Subgroups

The main motion during LB was significantly reduced in the "asymmetric" group compared with healthy subjects. Frequently, the real cause of the reduced ROM associated with neck pain is not known, but suggested reasons include mechanical changes in the tissues or pain inhibition.[27,28] Lee *et al.*[29] suggest that the location of neck pain affects quantitative parameters, as the rotation, during repeated testing, involves stretching of tissue on the side of pain. In the present study, the controls showed a smoother pattern than the "symmetric" group during AR for the conjunct LB. Previous studies showed similar results concerning changed qualitative parameters between controls and patients with different etiology of neck pain.[11,19,20] The present results showed smoother motions for the "asymmetric" group than the "symmetric" group and even, although not significant, compared with healthy controls. Further investigation is warranted to find an explanation for this puzzling result.

NDI and Neck Kinematics

The present study did not demonstrate strong correlations between NDI and neck kinematics. Kauther *et al.*[16] found no differences of CROM and maximal torque in the sagittal, frontal, and transverse plane between healthy controls and young neck pain patients with significant differences in NDI-scores. In contrast to these findings, Sarig-Bahat *et al.*[17] reported a direct relationship between the decrease in ROM in 25 CNPs and the degree of disability. Due to the biopsychosocial character of pain, the authors did not expect kinematic parameters to solely account for the degree of disability as measured by the NDI.

Age and Neck Kinematics

Although a statistically significant effect was demonstrated for age on several kinematic parameters, correlations were low. As such, age was not taken into account as a covariant in the statistical analysis in this study. Regarding the smoothness of movement, similar results were demonstrated by Oddsdottir *et al.*,[21] who found that the jerk-index was not substantially affected by age in a group of 182 asymptomatic persons. Nevertheless, various previous studies demonstrated age-related changes in cervical kinematics.[3,14,19–21,30,31] For example, Cattrysse *et al.*[20] demonstrated significant correlations with age in healthy subjects and in patients after cervical fusion surgery during AR and LB.

Methodological Considerations

Comparing results from the present study with former ones is difficult and can be misleading. The difference in the degree of disability may account for differences between the results of the present and former investigations. The participating patients only showed mild disability with a mean score of 19.50% (SD: ±12%) on the NDI that may explain the lack of significantly differentiating kinematics. On the contrary, Sjölander *et al.*[11] demonstrated significant jerkiness and irregular cervical movements in CNPs with moderate disability (mean: 37% ± 11%). Furthermore, Feipel *et al.*[19] found significant qualitative differences between healthy subjects and patients with cervical disc hernia. The disc pathologies in that study were all severe and required surgical treatment.[19] Pain experienced during movements could be a factor that troubles an objective endpoint of the movement and consequently confounds the results. In the present study, the average pain intensity of the patients was not assessed. Previous investigations showed no strong correlation between pain and cervical movements; unfortunately, these studies focused on quantitative parameters.[7,16] Nevertheless, Bogduk and Mercer[32] stated that pain has an influence on the position of the Instantaneous Rotation Centers. So, the influence of pain intensity on qualitative kinematic parameters remains unclear. In the present study, the magnitude of the coupled movements exceeded those of former studies. This discrepancy could possibly be due to the rotation sequence adopted for the angular representation of the three-dimensional rotation. Hof *et al.*[33] claimed that the outcome of Euler angles depends on the in advance chosen sequence. According to these researchers, standardization is desirable to avoid cross-talk. It is possible that the use of two local reference frames contributed to cross-talk. To account for this possible bias, the Euclidian norm, as a representation of global 3-D motion, was used in the present study. Three different researchers executed the measurements. Each set of movements were repeated three times in a fixed order to ensure enough interpretable data. These repetitions might have influenced the results. Although the instructions were standardized, a possible effect on the results due to the registration of the reference frames by different researchers cannot be estimated, as the inter-rater reliability is disputable.[34–36]

CONCLUSION

The kinematic results from this study suggest the existence of subgroups within CNPs. CNPs with a symmetrical pain pattern show significant poorer quality of movement, while those with asymmetrical pain show significantly lower quantitative characteristics. Given the diversity within the group of chronic nonspecific neck pain, it should be considered whether it is justified to compare CNPs as one group to healthy controls. The present results demonstrate that differences in kinematics in neck pain patients with symmetrical and asymmetrical pain location should be considered when developing and deciding treatment strategies. Subgrouping acute neck pain patients might equally be of help to clarify whether motor control impairment is a cause or rather the result of neck complaints.

➢ Key Points

- 3D cervical kinematics for active axial rotation, lateral bending, and flexion-extension can be investigated by analyzing and comparing quantitative and qualitative parameters in healthy subjects, CNPs, and subgroups of CNPs based on their pain location.
- Differences between healthy subjects and CNPs are mainly based on quantitative kinematic parameters
- CNPs with a symmetrical pain pattern showed significant poorer quality of movement, while those with asymmetrical pain show significantly lower quantitative characteristics.
- Subgrouping of CNPs based on pain location may be of help for further research.

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