Changed cervical kinematics after fusion surgery

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Abstract

Purpose Analyzing and comparing the range of motion and movement pattern of subjects who underwent an anterior cervical fusion using trabecular metal with control subjects.

Methods Three-dimensional kinematics of planar active axial rotation and active lateral bending of 50 experimental and 41 control subjects were registered by means of an electromagnetic tracking system.

Results Comparing the experimental group with the control group reveals that the range of the main motion component differs significantly ($p < 0.01$) during the active axial rotation and lateral bending movement. During active axial rotation, the coupled lateral bending motion component also differs between both groups. The root mean square value of the jerkiness (derivative of the acceleration) and de deviation from the 6-polynomial smoothed function of the main as well as the coupled motion component express the qualitative aspects of kinematics and are significantly different between the

experimental and the control group for both movements ($p < 0.05$).

Conclusions Subjects who have an anterior cervical fusion with trabecular metal show significant quantitative as well as qualitative differences in cervical kinematics during active axial rotation and lateral bending compared to control subjects.

Keywords Cervical spine · Surgical fusion · Kinematics · Trabecular metal

Introduction

Three-dimensional-kinematics of the cervical spine in patients who received spinal fusion surgery is poorly demonstrated. Most studies rely on the analysis of medical imaging to evaluate changed cervical spine kinematics [1, 2], and segmental changes due to fusion or prosthesis surgery have been demonstrated [3].

It is to be expected that surgical fixation of a motion segment may change cervical kinematics. However, it is not known whether kinematic changes relate mainly to quantitative aspects of the motion. Beside kinematic disturbances in quantitative aspects like Range of Motion (RoM) and motion coupling patterns, qualitative changes have been suggested [4–7]. Changes in motion sequence or the stability of the motion may be an expression of altered or disturbed proprioception or neuromuscular control inhibition. In addition, research on the global kinematics of the spine has demonstrated a reduction in the range of motion of the main motion component in the cervical spine due to age [8–11].

The present study intends to objectively demonstrate changes in kinematics after surgery. The range of motion, as well as the motion patterns in patients after anterior cervical fusion surgery is compared with healthy controls.

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Aspects of movement smoothness are expressed in quantitative measures to explore the kinematics beyond the level of quantitative kinematics as usually studied by the analysis of range of motion estimations.

This analysis will be relevant to take in consideration when analyzing the overall results of cervical arthrodesis compared to prosthesis.

Materials and methods

Subjects

A total of 91 persons participated in the study. The experimental group consisted of 41 persons among which 33 male (78%) and 8 female (22%) patients. The mean age of the participants was 52 years (± 12 years) ranging between 32 and 79. All patients had received a single or multi-level surgery. Patients were recruited during routine follow-up consults and kinematics were registered after informed consent was signed. The protocol was approved by the ethics committee of the Brussels University Hospital.

Two subgroups were defined: an experimental group with single-level fusion ($n = 27$) and one with patients with multi-level fusion ($n = 14$). Anterior cervical fusion was performed via the Smith–Robinson procedure using trabecular metal (TM 100™, Zimmer Spine, Minneapolis, MN, USA) without an anterior cervical plate.

Patients were included after consolidation of the fusion. This was achieved in every patient treated with anterior cervical fixation procedure and was confirmed with a plane X-ray (anterior–posterior and lateral view) by an independent radiological committee. The control group included 50 persons (20 male and 30 female) with a mean age of 52 years (± 16 years) ranging from 22 to 82 years.

Materials

Cervical kinematics were registered by means of the Flock of Birds electromagnetic tracking system (Ascension Technologies USA®). The system is able to capture 3D positional and orientation data from multiple sensors within a low-pulsed magnetic field. To avoid interference, all ferromagnetic materials were removed from the evaluation area and patients were positioned on a wooden chair [12, 13]. One sensor was mounted on the frontal part of the head by means of a Velcro strap, the second one was positioned on the sternum. Sensors were oriented in the frontal plane. The transmitter was positioned on a wooden frame in front of the subject, level with the sternum. Software was developed within the department to transform the system data into relative 3D Euler angles [14] expressing the orientation changes between head and thorax.

Methods

Participants were requested to first rotate the head from left to right three times consecutive and secondly to bend the head laterally left and right three times consecutive.

Movements had to be performed in a self-paced way and in an attempt to smoothly reach full actual endrange positions. Active endrange positions could be determined by pain or muscular restriction in case of patients.

All registrations of planar movements were performed three times. The first time, serving as an assimilation trial, the second as the actual data registration and the third as a back-up in case of technical errors (Fig. 1).

Data analysis

Data were stored in Microsoft Excel spreadsheets and kinematic processing was performed in a MathCAD 13 mathematical software routine. Eight different parameters were defined to describe the kinematic patterns in an objective way [15]. The range of motion was calculated for the main motion components (i.e. axial rotation resp. lateral bending) as well as for the coupled motion components (Fig. 2). The relationship between axial rotation and

Fig. 1 Experimental set-up

Fig. 2 Graphical representation of three consecutive movements during active axial rotation of subject 1

lateral bending motion components was analyzed by the cross-correlation between the main motion and the coupled motion components. The ratio between the main and coupled motion component was defined as the ratio between the standard deviations of both motion components and depicts the ratio over the whole motion trajectory [16].

Qualitative kinematic aspects associated to the smoothness of the motion were made operational by calculating the root mean square value of the jerk for each motion component (Fig. 3a). The Jerk index is the third derivative of the position and as such depicts the change in acceleration [17].

Standard Error of measurement on the deviation of the original data and a sixth polynomial function describing the curve was calculated as a second measure of smoothness (Fig. 3b) [4].

Individual kinematic data were statistically analyzed using SPSSv19 (SPSS Inc, USA). Normality of data distribution was checked using Kolmogorov–Smirnov Goodness-of-Fit test ($p < 0.05$).

To study the relationship with age, Pearson correlation and Spearman Rank Correlation coefficients were calculated according to the type of parameter data distribution. Differences between subjects and controls and between subgroups were analyzed using Analysis of CoVariance (ANCOVA) for parametric data and Mann–Whitney tests for non-parametric data.

Results

Axial rotation

The main axial rotation motion component is the only independent parameter, which correlates with age ($p < 0.00$). This correlation with age is present in the control as well as in the experimental group. As such, this parameter is considered as a co-variant factor in the statistical analysis of the axial rotation component.

In the experimental group, most kinematic parameters show significant differences with the control group, except for the cross-correlation and the ratio between the main axial rotation motion component and the coupled lateral bending component, and the range of motion of the coupled lateral bending movement (Table 1).

In addition, in the multi-level subgroup, the smoothness of the coupled lateral bending motion component differs from the controls and in the single level subgroup, the range of motion of the coupled flexion–extension motion is different from controls.

Lateral bending

Within the control group, the main lateral bending and coupled flexion–extension motion components correlate significantly with age. Consequently, these parameters are considered co-variants in the statistical comparison.

Fig. 3 **a** Speed, acceleration and jerk data of subject 1. **b** Raw and smoothed data and difference between both from subject 1

Table 1 Cervical kinematics during active axial rotation

	Control (<i>n</i> = 50)		Experimental (<i>n</i> = 41)			Arthrodesis multi-level (<i>n</i> = 14)			Arthrodesis single-level (<i>n</i> = 27)		
	Mean	SD	Mean	SD	Sign	Mean	SD	Sign	Mean	SD	Sign
Axial rotation											
Cross-correlation	0.50	0.71	0.43	0.73	NS μ	0.35	0.85	NS μ	0.46	0.67	NS μ
Ratio	16.59	10.71	12.23	7.89	NS	11.60	7.89	NS	12.55	8.01	NS
Flexion–extension component	6.89	2.63	11.01	4.20	*	10.81	5.04	**	11.12	3.80	NS
Axial rotation component	126.84	20.24	106.86	18.68	**£	95.81	14.83	**£	112.59	18.08	**£
Lateral bending component	12.42	7.04	13.63	6.88	NS	12.48	5.96	NS	14.23	7.35	NS
Variability of flexion–extension	0.41	0.19	0.73	0.44	**	0.58	0.31	*	0.80	0.48	**
Variability of axial rotation	2.29	1.01	3.09	1.37	**	3.53	1.45	*	2.87	1.30	*
Variability of lateral bending	0.77	0.35	1.11	0.55	**£	0.99	0.37	NS	1.17	0.62	**£
Jerk on flexion–extension	0.87	0.54	1.64	0.91	**	1.62	1.04	**	1.65	0.86	*
Jerk on rotation	1.11	0.48	2.71	1.61	**	2.85	2.08	**	2.64	1.35	**
Jerk on lateral bending	1.08	0.46	2.52	0.78	**£	2.49	0.56	**£	2.54	0.88	**£

£ Ancova, μ Mann–Withney *U* test, *sign* level of significance with ** $p < 0.01$ and * $p < 0.05$

Means and standard deviations are expressed in degrees

Jerk is an absolute value (smaller values indicate a more smooth movement)

Table 2 Cervical kinematics during active lateral bending

	Control (<i>n</i> = 50)		Experimental (<i>n</i> = 41)			Arthrodesis multi-level (<i>n</i> = 14)			Arthrodesis single-level (<i>n</i> = 27)		
	Mean	SD	Mean	SD	Sign	Mean	SD	Sign	Mean	SD	Sign
Lateral bending											
Cross-correlation	0.86	0.38	0.68	0.60	NS μ	0.64	0.61	NS μ	0.70	0.61	NS μ
Ratio	0.34	0.19	0.43	0.36	**£	0.50	0.41	* £	0.40	0.34	*£
Flexion–extension component	8.69	3.85	9.52	4.53	NS	9.25	5.23	NS	9.66	4.23	NS
Axial rotation component	19.63	8.42	24.21	14.74	**	23.53	13.66	**	24.56	15.52	**
Lateral bending component	64.13	20.71	60.07	18.06	**£	46.94	13.10	**£	66.87	16.59	**£
Variability of flexion–extension	0.57	0.42	0.56	0.32	NS	0.54	0.37	NS	0.57	0.30	NS
Variability of axial rotation	0.55	0.26	0.87	0.56	** μ	0.76	0.39	** μ	0.92	0.63	** μ
Variability of lateral bending	1.63	0.59	2.49	1.48	**£	2.26	1.12	** £	2.61	1.64	**£
Jerk on flexion–extension	0.65	0.45	1.31	1.24	**	1.16	0.72	**	1.39	1.44	**
Jerk on rotation	1.03	0.52	2.58	0.71	*	2.64	0.66	NS	2.54	0.74	*
Jerk on lateral bending	0.69	0.33	2.11	1.17	**	2.52	1.68	**	1.90	0.75	**

£ Ancova, μ Mann–Withney *U* test, *sign* level of significance with ** $p < 0.01$ and * $p < 0.05$

Means and standard deviations are expressed in degrees

Jerk is an absolute value (smaller values indicate a more smooth movement)

Differences in kinematic parameters are demonstrated between surgery patients and control subjects for several aspects of kinematics (Table 2) except for the cross-correlation between the main axial lateral bending and the coupled rotation motion components, and for range of motion of the coupled flexion–extension motion component and of the smoothness the movement expressed by the deviation from the polynomial function of this coupled flexion–extension motion component.

The single-level fusion patients show an identical pattern of differences with controls as the total group.

Nearly similar results are demonstrated within the group of multi-level fusion patients except for an additional significant difference with controls in the smoothness of the coupled axial rotation motion component expressed by the jerk parameter.

Coupling patterns are ipsilateral if the value of the cross-correlation is positive and contralateral if it is negative.

In the present study, the control subjects demonstrate ipsilateral coupling patterns during active axial rotation in 38 out of 50 subjects (mean cross-correlation 0.50 ± 0.71) and in 48 subjects during active lateral bending movements (mean cross-correlation 0.86 ± 0.38). The experimental group shows an ipsilateral coupling during axial rotation in 31 out of 41 subjects (CC: 0.43 ± 0.73) and in 35 subjects during active lateral bending (CC: 0.68 ± 0.60).

Summarizing the results, the following can be stated. The patient group clearly shows differences in 3D-kinematics compared to the control subjects as expressed in most of the examined parameters. However, the cross-correlation expressing the relationship between main and coupled motions shows no significant differences and, as such, could not differentiate between patients and healthy subjects.

During lateral bending, the coupled flexion–extension and its derived smoothness parameter do not differentiate between groups.

All subgroups show nearly similar patterns of differences in kinematics compared to the control group with most parameters showing significant differences. During active axial rotation, ranges of motion are slightly but significantly reduced for the main axial rotation motion component, even after controlling for co-variance due to age.

While performing lateral bending, patients seem to move slightly out of plane resulting in a reduced main lateral bending motion component and increased coupled axial rotation, except for the single level fusion patients. Although the differences are relatively small, they are statistically significant.

Differences between patients are demonstrated in quantitative parameters (ratio and range of motion of 3D-motion components) as well as in qualitative aspects as the smoothness of the motion (expressed in Jerk values and rms values for the deviation from the sixth polynomial smoothing curve).

Discussion

This study intended to investigate quantitative as well as qualitative aspects of kinematics within a group of patients who underwent cervical surgery.

The comparisons between patients and controls demonstrate mainly reduced axial rotation mobility in the group with fusion surgery. The range of motion values show a mean axial rotation motion component of $126.8^\circ (\pm 20.2^\circ)$ compared to $106.9^\circ (\pm 18.7^\circ)$ in the experimental group.

During lateral bending many aspects of kinematics showed differences ($p < 0.01$) and the lateral bending mobility as well the smoothness of the motion are reduced

in the experimental group. The mean range of motion of the lateral bending component is $64.1^\circ (\pm 20.7)$ in healthy control subjects, while in the experimental cervical surgery group mobility was reduced to $60.1^\circ (\pm 18.1)$. However, coupled motion components have increased in the experimental group. This would indicate that cervical surgery patients move relative out of plane compared to the control group's subjects.

Comparison of the results with literature reveals that the range of motion (RoM) of the main axial rotation motion component data from the experimental group in this study are lower than the results of the study of Assink et al. [18] who reported $133.8 (\pm 13^\circ)$ in a group of healthy subjects and $122.5^\circ (\pm 12.8^\circ)$ in a group of symptomatic patients. The same authors [18] also indicated larger RoM data for the lateral bending movements reporting $79.6^\circ (\pm 12.2^\circ)$ in their control group and $60.2^\circ (\pm 14^\circ)$ in the experimental group. However, a similar trend towards a clear reduction of the main motion component in patients was observed.

It has been demonstrated that RoM is subjected to diurnal variations and that differences between evaluators may rise to 10° [18]. From normative data [9, 10, 19] one can expect normal axial rotation ranges between 139° and 149° and lateral bending mobility ranging between 73° and 93° . The results of the present study show lesser RoM results in the control group. Differences in registration techniques as well as kinematic data calculations might lead to differences in results between studies.

Previous studies have demonstrated coupling between main axial rotation and coupled lateral bending to be mainly ipsilateral in healthy subjects [10, 19] although contralateral coupling patterns have been reported in about 30% of the population [10]. In the present study, the coupling patterns is ipsilateral if the value of the cross-correlation is positive and contralateral if it is negative [15].

Percentages of ipsi- and contralateral coupling in healthy subjects are similar as reported in literature except during lateral bending. This may indicate ipsilateral coupling patterns during lateral bending to be slightly more specific for patients after cervical surgery for fusion.

The main limitations of the present study are the limited number of multi-segment fusions. It is, however, interesting to notice that in single level as well as in multilevel fusions clear kinematic changes were demonstrated. A comparison between both groups could not be performed due to statistical lack of power. To analyze the effect of single versus multiple level interventions a 3D analysis of segmental kinematics should be performed based on medical imaging data.

Moreover, no pre-surgical data were present. Therefore, the relative beneficial effect of the surgical intervention on

cervical kinematics could not be demonstrated in the present protocol.

Age related changes in cervical kinematics as reported in literature [8–11] were clearly present in the RoM of the main motion component data in the present study. These correlations have been accounted for when comparing the results of the experimental group with controls.

The jerk parameter is an index of variation in speed and expresses the stability of the motion [5]. The deviations between raw and sixth polynomial smoothed data equally represent the stability of the motion [4]. As such, these kinematic parameters are quantitative representations of the quality of the movement. The root mean square value of the jerk data and the deviation from the smoothing polynomial are objective tools to estimate the quality of the motion and may be an expression of motor control aspects. From the presented data, differences between controls and cervical patients can be demonstrated in the quality of the motion. Qualitative parameters may be an additional tool to differentiate pathological from normal conditions and proved to be useful in other patient groups as well [5].

The use of cervical prosthesis is gaining increasing attention based on the rationale of conservation of regional and segmental motion [20, 21]. Initial clinical investigations report good results concerning the preservation of function and motion in the sagittal plane on a short term [2, 3]. Long term effects and risks of adverse effects are not yet known [22].

Although significant kinematic changes were demonstrated in patients after cervical fusion surgery, the impact of this change on the quality of life still has to be examined. Additional information on daily life activities can be gathered by disability and quality of life questionnaires and should be correlated with kinematic data to explore this issue. Moreover, a pre- and post surgery evaluation of kinematics as well as quality of daily life should be performed. Although cervical kinematics after fusion surgery may be different from healthy controls as demonstrated in the present study, surgery may have largely improved the quantity and quality of movement as well as the quality of living compared to the pre-surgery pathological status.

The results of this study indicate differences in the quantity as well as in the quality of movement in patients with cervical fusion surgery. These changes were most consistently present in the main motion component during axial rotation and lateral bending. Moreover, the results indicate that cervical arthrodesis patients tend to move relatively out of plane. Even in patients with sufficient, adequate or nearly normal mobility, changes in qualitative aspects of cervical kinematics may be present and potentially related to quality of functioning. The qualitative changes demonstrated in the present study are important to consider when trying understanding the limitations in daily

life and aspects of quality of life of patients after fusion surgery. Surgeons may have to look beyond the adequacy of restored range of motion to evaluate the results of their intervention.

Future research should focus on these aspects to investigate and understand the possible superiority of one technique over the other and may consider the use of rehabilitative exercise to try to improve quality of motion.

Conclusion

The results of the present study demonstrate significant differences in quantitative as well as in qualitative aspects of cervical kinematics after surgery for spinal fusion according to the Smith–Robinson procedure.

Current differences relate to the RoM of the main as well as of the coupled motion component, and to the sequence of the motion.

Whether these kinematic changes influence functional behavior could not be addressed from the present study. Kinematic changes do not necessarily imply an impact on quality of life. Moreover, the impact of these kinematic changes are probably much less disabling than the pre-existing pathology.

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