Vrije Universiteit Brussel

Università degli Studi di Genova

In collaborzione con Libera Università di Brussel

FACULTY OF MEDICINE AND PHARMACOLOGY

FACOLTA' DI MEDICINA E CHIRURGIA

Erasmus-program

Master disordini muscolo scheletrici

The effects of Anterior Cervical Decompression and Fusion surgery on cervical spine kinematics and disability.

Masterthesis in partial fullfilment of Erasmus Exchange program by:

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Academic Year: 2010-2011

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Abstract

Objective
The effects of the Anterior Cervical Decompression and Fusion (ACDF) procedure on both the cervical spine Range Of Motion (ROM) and disability haven't been studied in detail.
The aim of this study was to compare the kinematics of active cervical spine movements performed in the frontal and horizontal planes between a group of patients who underwent ACDF and a group of healthy subjects. Furthermore the Neck Disability Index (NDI) was reported by the patients after surgery in order to investigate the correlation between the disability and kinematic changes.

Materials and Mehtods
Data from 50 patients who underwent ACDF and 50 healthy subjects were acquired by using the Flock of Birds (FoB), a non-invasive, electromagnetic, six degrees-of-freedom tracking device. The movements on the main axis and the coupled movements were analyzed by eleven parameters: the Cross-Correlation, the Ratio, the Range of Motion (ROM), the Root Mean Square of the Jerk (RMSJ) and the Standard Deviation of the Error (STDERR) of the three motion components. In addition the patients reported NDI after surgery. The data were compared with both parametric and non parametric tests due to the different distribution among all the data collected.

Results
A significant inverse correlation ($p<0,05$) between the age, ROMy and ROMz was found in the rotation and lateral bending movement, respectively. There was a significant difference ($p<0,05$) between the groups in the rotation for nine out eleven parameters. There was a significant difference ($p<0,05$) between the groups in the lateral bending for seven out eleven parameters. No significant correlation was found between the age and NDI score and between the eleven parameters and NDI score.

Conclusions
The age had an inverse correlation with ROM on main axis for the rotation and lateral bending. The ACDF procedure seemed to affect ROM on main axis in both the axial rotation and lateral bending. It also seemd to have a negative effect on quality of both the movements. No correlation among NDI score, the age and the cervical spine kinematics was found.

Introduction

Decompression and fusion of the cervical spine for treatment of different problems such as radiculopathy, myleopathy and stenosis or acute instability is commonly achieved through the Anterior Cervical Decompression and Fusion (ACDF) procedure [12-17, 20]. The goal of the fusion is to eliminate movement to the pathological segments and, by doing this, to reduce stress to the correlated neural structures [13]. However, it is currently unclear how the elimination or reduction of segmental motion achieved by the fusion surgery translates to the patients' global Range Of Motion (ROM) [13]. It can be stated that there is a need for information on the effects of ACDF on the cervical spine kinematics and the patients' quality of life. Hilibrand et al. [14] investigated the effects of ACDF on the cervical spine Passive Range Of Motion (PROM). The results showed a significant difference between the pre-operative and the post-operative PROM and significant difference between the post-operative PROM and the healthy subjects. The authors also found that cervical spine fusion of up to four levels did not effect overall PROM. In a very recent study Bell et al. [13] examined the Active Range Of Motion (AROM) using a magnetic tracking device among healthy, pre-operative and post-operative subjects. In addition NDI was reported by all patients. The results showed a decreasing trend in AROM as the number of operated levels increased, a decreased AROM in the pre-operative group compared to the control group, a late post-operative AROM similar to the control group for patients operated at only one level but not for those operated at more than one level. There was also a significant improvement of the post-operative NDI score compared to the pre-operative score. A significant inverse correlation between AROM and NDI showed that the disability level increased as AROM decreased. The authors then suggested that future work was needed to describe the dynamic in vivo segmental kinematics following an ACDF procedure. The reason was to study the effect of surgery on adjacent levels of cervical spine. In addition, they stated there was still a need for improvement of the ACDF procedure beacause, on average, the post-operative patients did not report a NDI surveys indicating "no disability" (score from 0 to 4). The results of Hilibrand et al. and Bell et al. were very similar except for the influence of the number of levels operated on cervical spine ROM. Bell et al. [14] stated that difference in methods could explain this discrepancy. In fact these two studies investigated AROM, where the subjects voluntary moved their head until pain was felt or until the end of ROM, and PROM, where an external torque was applied to the head of the patients, and this could explain the difference.

Flock of Birds

Different methods, such as optical techniques, radiography, electrogoniometry and ultrasonic techniques have been developed to obtain a reliable measurement of cervical spine ROM. Yet, there is no golden standard for the measurement of spinal ROM [21-26]. The Flock of Birds (FoB) has been studied as a tool to assess global cervical ROM in vivo. Basically it is a non-invasive, electromagnetic, six degrees-of-freedom tracking device; a transmitter creates a pulsed direct current electromagnetic field that is simultaneously measured by one or multiple sensors. From the measured electromagnetic field characteristics, each sensor independently computes its position and orientation. The overall rotational data can be displayed in real time on a personal computer [21, 22]. FoB is one of the few instrument that is suitable for measuerment of relative 3-dimensional joint rotation and it also makes possible to isolate the contribution of upper thoracic spine movements [21]. FoB showed to have an high intra-examiner and a fair-to-high inter-examiner reliability [21] and to be sufficiently precise [24]. Koerhius et al. [24] stated that FoB had a very small measurement error (2°–4°) within one session but the measurement error between sessions was substantially larger (varying from 5° to 15°). Assink et al. [25] reported a sufficient inter-observer reliability for measuring AROM of axial rotation in neutral position, flexion, extension and lateral bending. Gelialis et al. [22] bescribed FoB as a reliable, non-invasive and reproducible method to measure the cervical ROM and its use was "*well suited for the assessment of various degenerative and traumatic disorders of the cervical spine. It could also be performed in the evaluation of post-operative results in cervical spine surgery as a function of time and in the evaluation of the influence of different therapeutic procedures postoperatively*".

The Neck Disability Index

NDI is a 10-item questionnaire addressing functional activites, recreational activites and a number of sympotms such as pain, headache and concentration and it's commonly used to assess disability and pain in patients with neck pain [1-9,15 ,16 ,19]. It was developed by Vernon and Mior in 1991 from a questionnaire used for low back pain, the Oswestry Disability Index [8]; each item is scored from 0 to 5 , the higher the score the greater the disability. Vernon and Mior [8] gave this interpetation of the score:

- 0 to 4 no disability.
- 5 to 14 mild disability.
- 15 to 24 moderate disability.
- 25 to 34 severe disability.
- > 35 complete disability.

Although this classification of the NDI score is often used in literature, no process was described for how these ratings were derived and no validation of these categories was performed [2].
The psycomethric properties of NDI and its application in groups of patients undergoing cervical spine surgery have been studied by different authors. Mc Carhty et al. [6] stated that NDI had a good construct validity and test-retest reliability and was also comparable to SF-36 which is considered to be the golden standard for generic health assessment. Carreon et al. [4] calculated the Minimal Clinically Important Difference (MCID) and Substantial Clinical Benefit (SCB) of NDI in a group of patients undergoing cervical spine fusion. SCB is a new concept which the authors defined, referring to Glassman et al – 2008, as "*the number of points a patient's score has to change for the patient to tell that he is much better*". MCID resulted to be 8 points while SCB 10 points; these values were specific for this population of patients. Peolsson et al. [16] stated that NDI was the most influential pre-operative and short-term variable for predicting short-term and long-term outcome respectively. This means that a low disability based on NDI before surgery, and even more a low NDI score at the short-term outcome, was a useful predictor for a successful long-term outcome of ACDF. So it's possible to conclude that the application of NDI is recommended in patients undergoing cervical spine surgey for radiculopathy, myelopathy or degenerative disorders such as stenosis, spondylosis and disc herniation [15, 16, 19]. Moreover since 2008 NDI has been translated and validated in twenty-two different langueges [19] meaning that its use is almost worldwide. As a general rule, the value of MCID should range between 3 and 5 [19].
See Addendum 2 for a copy of NDI scale.

Anterior Cervical Decompression and Fusion procedure

ACDF is a surgical technique commonly used for different problems of cervical spine such as radiculopathy, myleopathy and stenosis or acute instability [12-17, 20]. An anterior incision is performed to expose the pathological level/levels. In order to decompress the neural structures the surgeons then removes the intervertebral disc and sometimes also the vertebral body. After the decompression the portions removed must be reconstructed; this means that a bone graft is inserted withtin each disc space to promote the formation of a living bridge of bone between the previously distinct vertebrae. Surgeons may use either a patient's own bone (autograft) or banked human cadaver bone (allograft), or a synthetic scaffold into which bone graft may be inserted (metal or carbon fiber cages). Despite its common use this technique has some potential associated complications such as post-operative dysphagia, hematoma and recurrent laryngeal nerve palsy but all of them can be successfully managed in the majority of the cases [18].

For a more detailed desciption of ACDF procedure see Addendum 3.

Cervical spine: global range of motion

The functional anatomy and kinematics of the cervical spine have been studied by many authors. Bogduk et al. [18] described the anatomy and the kinematics of the cervical spine and divided it in four units: the atlas, the axis, C2-C3 junction and the remaining typical cervical vertebrae. But this paper addressed to the global ROM of cervical spine so this part shows some data of global cervical spine ROM taken from different works. Feipel et al. [10] analyzed the three-dimensional cervical ranges and patterns, i.e. coupled movements, in 250 asymptomatics volunteers by using an electrogoniometer. Flexion-extension average ROM was 122°±18° and the movements were relatively pure, almost without coupled movements. Lateral bending average ROM was 88°±16° and it was accompained by homolateral rotation which averaged 13°-25°. The rotation displayed the larger global ROM as compared to the flexion-extension and the lateral bending: average ROM of rotation in neutral position was 144°±20° and the coupled movements were not significant. In order to study the inter-observer reliability of the FoB device Assink et al. [25] analyzed the global ROM in a group of asymptomatic and symptomatic subjects. Two observers performed the measurements. The mean AROM and standard deviation in the asymptomatic group resulted to be:

- for rotation in neutral position: 135.3°±12.9° and 132.4°±13.2°.
- for flexion-extension: 127.8°±14.2° and 129.6°±15.1°.
- for lateral bending: 79.6°±12.2° and 77.7°±13.3°.

In order to establish the normal variation of AROM and PROM measured with the FoB device over time Bergman et al. [23] recruited 48 subjects without known history of neck pain or shoulder pain and collected data at three different sessions: a baseline measurement (T0) and two follow-ups measurements, after 6 (T1) and 12 weeks (T2). The mean AROM and standard deviation at T0, T1 and T2 were:

- rotation: 135.4°±15.6°, 135.1°±16.7° and 136°±16.7°.
- flexion-extension: 130.8°±16.3°, 125.4°±19° and 126.5°±17°.
- lateral bending: 78.1°±14.9°, 77.5°±14.4 and 77.4°±15.1°.

In a study of Assink et al. [26] 50 healthy subjects were recruited and AROM data were collected by a single observer with two different tools: the FoB device and a Cybex Electronic Inclinometer-320. The measurement sessions were conducted three times in a 6-week interval. The mean AROM and standard deviation of FoB were:

- flexion-extension: 130.8°±16.3°, 125.1°±19.2° and 126.6°±17.2°.
- lateral bending: 77.4°±14.2°, 77.2°±14.3° and 77.4°±15.1°.
- rotation in neutral position was not collected.

Gelialis et al. [22] investigated the reliability and reproducibility of the FoB with a comparison of AROM data obtained with FoB and with an inclinometer. The mean AROM and standard deviation of FoB data were:

- flexion-extension: 130.0°±19.7°.
- lateral bending: 79.4°±11.0°.
- rotation: 140.9°±15.9°.

Materials and Methods

Fifty subjects who underwent cervical spine surgery (experimental group) and fifty healthy subjects without previous history of neck problems or surgery (control group) were included in the study. In the experimental group there were 39 men and 11 women and the mean age was 55±14 years (range 32-84). Six patients had only laminectomy, twenty-seven had only arthrodesis at one level, fourteen had only arthrodesis at more than one level, two had laminectomy combined with arthrodesis at one level and only one patient had laminectomy combined with arthrodesis at four levels. In the control group there were 20 men and 30 women and the mean age was 52±16 years (range 22-82). An electromagnetic tracking device, the Flock of Birds, was used to assess kinematics in each subject. An electromagnetic sensor was placed on the forehead using a velcro to track the head's movement. Another sensor was placed on the sternum to monitor trunk's movement.

Figure 1: the FoB device applied on a subject. Two sensors were placed on the forehead and on the sternum. The transmitter was placed in front of the subject.

The transmitter was placed on a table in front of the subjects (Figure 1). The difference between the two sensors described the motion of the head relative to the trunk which is equivalent to global neck movement. The subjects were sitting on a chair facing an empty wall and were asked to assume a comfortable and uprigth position. Each movement was performed three time and only the best of the three acquisition was used for the statistical analysis. The subjects were instructed to conduct a maximal movement at a normal velocity until the end of ROM was reached or pain was felt and also to move their head only in the required direction avoiding compensatory movements with the thoracic or lumbar spine. AROM in the horizontal and frontal planes, i.e. active plannar axial rotation and active plannar lateral bending, was collected in both groups. The movement on the main axis and the coupled movements were analyzed. The axes were definded as follows: x-axis, y-axis and z-axis were the main axis for the flexion-extension, the axial rotation and the lateral bending, respectively. Eleven parameters were taken in consideration to describe each movement. The *Cross-correlation* between the main axial rotation (or lateral bending) movements and the coupled lateral bending (or axial rotation) was calculated: it ranges from -1 to 1 and it indicates whether the coupled movement is controlateral or ipsilateral. The *Ratio* between the axial rotation and lateral bending motion components: it was defined as the ratio between the standard deviations of the axial rotation and lateral bending motion components. The *ROM* was calculated for the main axial rotation (or lateral bending) movements as well for the coupled lateral bending (or axial rotation) and the flexion-extension motion components. The *RMSJ* (Root Mean Square of the Jerk) on three axes was calculated.: the jerk is the variation in acceleration over time; a smooth motion has a lower jerk [11]. The *STDERR* (Standard Deviation of Error) on three axes was calculated; an explanation on how the STDERR is calculated was given by Feipel et al. [27].

The patients were also asked to report NDI after surgery as a measurement of level of disability. Both the pre-operative ROM and NDI data could not be collected in this cross-sectional study.

All calculations were made in Mathcad-professional software and the data were then transferred in an Excel database.

An example of how the analysis of data was conducted is given in Addendum 4.

<u>Statistical analysis</u>

For all statistical calculations SPSS 17.0 software was used.

The Kolomogorov-Smirnov goodness of fit test was performed in order to verify the normal distribution of the eleven parameters. Both parametric and non-parametric tests were used according to the results of the Kolmogorov-Smirnov test and the nature of the data. The correlation between the age, the eleven parameters and NDI score was analyzed with respectively Pearson correlation test and Spearman correlation test. The difference between the two groups was analyzed with Analysis of Variance (ANOVA), Analysis of Covariance (ANCOVA) or Mann-Whitney test.

Results

The mean and the standard deviation (SD) of the eleven parameters for the axial rotation and the lateral bending in both groups are shown in Table 1 and Table 2. The number of the subjects who had a positive Cross-correlation, which means an ispilateral coupling pattern, is also reported as a descriptive statistic.

Axial rotation
Six parameters had a normal distribution in both groups. So it was possible to use parametric tests in the statistical analysis of these parameters. Four parameters had a normal distrbution only in one group and one parameter did not have a normal distribution in both groups: for these variables non parametric tests were used. Only ROMy had a significant inverse correlation with age ($p<0,05$) in both the control ($r = -0,5$) and experimental group ($r = -0,4$). Significant differences between the experimental and control group are present for all parameters ($p<0,05$) except for ROMz and the Cross-Correlation (see Table 1).

Lateral bending
Six parameters had a normal distribution in both groups. So it was possible to use parametric tests in the statistical analysis of these parameters. Three parameters had a normal distribution only in one group and two parameters did not have a normal distribution in both groups: for these variables non parametric tests were used. Only ROMz had a significant inverse correlation with age ($p<0,05$) in both the control ($r = -0,51$) and experimental group ($r = -0,38$). RMSJy had a significant correlation with age ($p<0,05$) but only in the control group. Significant differences between the experimental and control group are present for all parameters ($p<0,05$) except for the Cross-correlation, the Ratio, ROMx and STDERRx (see Table 2).

NDI
The mean and SD of NDI score among all fifty patients was 11±12 and the range was 0-50. There was not a significant correlation between NDI score and the eleven parameters except for RMSJz in the axial rotation ($p<0,05$).

Laminectomy and Arthrodesis
The experimental group was divided in three sub-groups: the patients who had only laminectomy, those who had only arthrodesis at one level and those who had only arthrodesis at more than one level. The low number of patients in each group did not allow a statistical comparison and only desciptive statistics are reported. Table 3 and Table 4 show the mean and SD of NDI score, the range of NDI and the mean and SD of the eleven parameters for the axial rotation and the lateral bending in the three sub-groups.

NDI sub-groups
The experimental group was also divided in five sub-groups based on the classification of NDI score by Vernon and Mior [8]. Once again the low number of patients in each group did not allow a statistical analysis and only descriptive statistics are reported. Table 5 and Table 6 show the mean and SD of the eleven parameters for the axial rotation and the lateral bending in the five NDI sub-groups.

Table 1: mean±SD of the eleven parameters in the two groups for the axial rotation.

	Experimental group	Control group
Cross-correlation	0,44±0,72 ; n =39	0,5±0,71 ; n=38
Ratio *	11,65±7,68	16,62±10,7
ROMx *	11,3±4,85	6,88±2,65
ROMy * #	102,12±21,41	126,77±20,33
ROMz	14,23±7,83	12,4±7,06
RMSJx *	1,59±0,89	0,88±0,56
RMSJy *	2,75±1,6	1,13±0,55
RMSJz *	2,51±0,78	1,07±0,45
STDERRx *	0,84±0,76	0,4±0,19
STDERRy *	3,1±1,37	2,28±0,98
STDERRz *	0,64±0,25	0,52±0,21

* = significant difference ($p<0,05$).
# = significant inverse correlation with age ($p<0,05$).
n = subjects who had a positive Cross-Correlation.

Table 2: mean±SD of the eleven parameters in the two groups for the lateral bending.

	Experimental group	Control group
Cross-correlation	0,73±0,57 ; n=44	0,86±0,38 ; n=48
Ratio	0,52±0,48	0,34±0,19
ROMx	8,81±4,27	8,63±3,89
ROMy *	24,45±14,22	19,64±8,43
ROMz * #	57,09±19,01	64,14±20,71
RMSJx *	1,24±1,14	0,66±0,45
RMSJy *	2,33±0,67	1,01±0,48
RMSJz *	1,75±0,86	0,69±0,33
STDERRx	0,53±0,3	0,57±0,42
STDERRy *	0,9±0,58	0,57±0,26
STDERRz *	1,63±0,75	1,23±0,51

* = significant difference ($p<0,05$).
# = significant inverse correlation with age ($p<0,05$).
n = subjects who had a positive Cross-Correlation.

Table 3: axial rotation; mean±SD of the eleven parameters, mean NDI score and range of NDI in the three sub-groups of patients.

	only laminectomy	only arthrodesis n=1	only athrodesis n>1
n° patients	6	27	14
NDI (mean±SD)	13±12	10±11	10±12
NDI (range)	0-28	0-40	0-36
Cross-correlation	0,66±0,78 ; n=5	0,46±0,68 ; n=21	0,36±0,85 ; n=10
Ratio	5,64±3,77	12,61±8,07	11,67±8,1
ROMx	14,01±7,37	11,06±3,79	10,67±4,89
ROMy	91,27±14,51	112,55±18,16	95,09±15,01
ROMz	22,65±9,39	14,23±7,35	12,48±5,96
RMSJx	1,39±0,85	1,6±0,81	1,63±1,07
RMSJy	2,15±0,83	2,0±1,54	2,81±2,09
RMSJz	1,94±0,66	2,68±0,88	2,5±0,59
STDERRx	1,82±1,68	0,79±0,47	0,59±0,28
STDERRy	3,71±1,49	3,42±3,26	3,52±1,46
STDERRz	0,82±0,26	0,65±0,25	0,61±0,21

n = subjects who had a positive Cross-Correlation.

Table 4: lateral bending; mean±SD of the eleven parameters, mean NDI score and range of NDI in the three sub-groups of patients.

	only laminectomy	only arthrodesis n=1	only athrodesis n>1
n° patients	6	27	14
NDI (mean±SD)	13±12	10±11	10±12
NDI (range)	0-28	0-40	0-36
Cross-correlation	0,96±0,05 ; n=6	0,69±0,63 ; n= 23	0,65±0,61 ; n=12
Ratio	0,59±0,52	0,43±0,37	0,52±0,4
ROMx	7,15±1,87	9,53±3,97	9,23±5,19
ROMy	25,31±15,25	25,16±15,35	22,84±13,17
ROMz	48,48±12,73	66,56±17,3	46,94±13,1
RMSJx	0,91±0,25	1,43±1,45	1,16±0,68
RMSJy	2,12±0,36	2,37±0,7	2,46±0,75
RMSJz	1,47±0,43	1,76±0,71	1,88±1,27
STDERRx	0,51±0,21	0,57±0,3	0,53±0,36
STDERRy	1,06±0,73	0,9±0,62	0,76±0,37
STDERRz	1,62±0,38	1,58±0,71	1,75±0,95

n = subjects who had a positive Cross-Correlation.

Table 5: axial rotation; mean±SD of the eleven parameters in the five NDI sub-groups.

	NDI 0-4 no disability	NDI 5-14 mild disability	NDI 15-24 moderate disability	NDI 25-34 severe disability	NDI > 35 complete disability
N° patients	25	13	5	4	3
Cross correlation	0,33±0,74 ; n=18	0,51±0,78 ; n=10	0,67±0,54 ; n=4	0,44±0,96 ; n=3	0,73±0,23 ; n=3
Ratio	13,11±8,04	10,77±8,25	11,23±7,26	6,27±5,59	11,24±4,21
ROMx	11,23±5,06	11,57±4,18	9,75±2,11	13,26±73,5	10,6±7,73
ROMy	103±20,61	112,57±13,82	100,8±23,12	87,5±16,64	71,17±30,21
ROMz	12,11±5,63	17,2±9,02	13,83±7,64	22,42±11,72	8,75±4,19
RMSJx	1,67±1,1	1,69±0,73	1,3±0,59	1,4±0,45	1,18±0,57
RMSJy	2,97±2,01	2,64±1,1	3,22±1,06	1,74±0,45	1,95±0,49
RMSJz	2,64±0,79	2,72±0,82	2,18±0,29	1,68±0,66	2,12±0,43
STDERRx	0,93±1	0,78±0,38	0,65±0,27	0,93±0,71	0,55±0,43
STDERRy	3,12±1,34	3,52±1,55	3,02±1,45	2,58±1,03	1,87±0,58
STDERRz	0,62±0,23	0,73±0,26	0,62±0,34	0,62±0,28	0,46±0,14

n = subjects who had a positive Cross-Correlation.

Table 6: lateral bending; mean±SD of the eleven parameters in the five NDI sub-groups.

	NDI 0-4 no disability	NDI 5-14 mild disability	NDI 15-24 moderate disability	NDI 25-34 severe disability	NDI > 35 complete disability
N° patients	25	13	5	4	3
Cross correlation	0,83±0,42 ; n=23	0,65±0,69 ; n=11	0,47±0,69 ; n=4	0,95±0,06 ; n=4	0,34±1,13 ; n=2
Ratio	0,58±0,46	0,36±0,21	0,13±0,07	0,45±0,32	1,39±0,92
ROMx	8,41±3,84	10,57±5,48	6,93±1,74	8,27±1,35	8,4±6,97
ROMy	27,97±16,29	22,54±11,82	10,47±3,39	21,64±10,07	30,48±4,53
ROMz	53,6±19,07	67,67±13,55	68,28±16,47	52,38±9,97	28,01±13,73
RMSJx	1,24±0,77	1,58±1,89	1,13±0,82	0,78±0,49	0,66±0,03
RMSJy	2,26±0,7	2,38±0,71	2,34±0,76	2,31±0,57	2,74±0,62
RMSJz	1,84±1,08	1,75±0,52	1,76±0,7	1,41±0,56	1,42±0,73
STDERRx	0,52±0,28	0,67±0,36	0,31±0,18	0,43±0,11	0,5±0,45
STDERRy	0,98±0,69	0,91±0,43	0,58±0,14	0,62±0,1	1,16±0,89
STDERRz	1,55±0,6	1,89±1	2,06±0,59	1,36±0,53	0,82±0,23

n = subjects who had a positive Cross-Correlation.

Discussion

The goal of this study was to compare the kinematics of active cervical spine movements performed in the frontal and horizontal planes among fifty patients who underwent ACDF surgery and fifty healthy subjects. Furthermore NDI was reported by patients to study the correlation between the disability and kinematic changes.

In this study the ROM values of the control group were in line with the values of global cervical ROM of previous study [10, 22, 23, 25, 26].

Based on interpretation of the Pearson and Spearmon correlation tests, the age seemed to affect

ROM on the main axis but not ROM of the coupled motion components: this finding is similar to another one of a previous research of the group on mechanical neck pain [28, 29].
The ACDF procedure seemed to affect ROM on the main axis of both the axial rotation and the lateral bending: in the experimental group ROMy was significantly smaller ($p<0,05$) for the axial rotation and ROMz was significantly smaller ($p<0,05$) for the lateral bending (see Table 1 and Table 2). The surgery may have had an influence also on the quality of movement. For the axial rotation, ROMx was significantly greater ($p<0,05$) in the experimental group which means that the patients performed this movement with a greater amount of coupled flexion-extension. The patients seemed to be less able to performe a "pure" rotation. There was not a significant difference between the two groups for ROMz, i.e. coupled lateral bending. As a consequence, the Ratio was significantly smaller in the experimental group. Taking in consideration the lateral bending, ROMz was significantly smaller ($p<0,05$) and ROMy was significanlty greater ($p<0,05$) in the experimental group. This means that the patients performed a reduced lateral bending with a greater amount of coupled rotation. As a consequence the Ratio was not significantly different.
The jerk is defined as the variation in acceleration over time; a smooth motion has a lower jerk. RMSJ on the three axes was significantly higher in the experimental group for both the axial rotation and lateral bending. This indicated that the experimental group performed less smooth movements than the control group, a finding similar to the one of Sjolander et al. [11] on patients with chronic idiopathic neck pain of insidious onset or whiplash associated disorders. Again the surgery seemed to affect also quality of movement, not only quantity.
The Cross-correlation was not significantly different in both the axial rotation and the lateral bending and the mean was positive in both the experimental and control group indicating an ipsilateral coupling pattern. But since the Cross-correlation ranges from -1 to 1, reporting only the mean does not give a complete description of the phenomenon. That's why the number of patients with a positive Cross-correlation was reported. Although no statistical analysis was done on this variable, a general trend could be observed: the presence of a postive Cross-correlation in most cases, i.e. ipsilateral coupling pattern. The surgery seemed to do not have a significant effect on the coupling pattern.
No significant correlation was found between NDI score, the age and the cervical spine kinematics. This was not in line with the initial hypothesis; infact we expected to find an association between higher disability and kinematic changes. This finding could be explained by the fact that statistical analysis was conducted without taking in consideration the number of levels operated and the different NDI score. In a recent study Bell et al. [13] analyzed AROM in a group of patients who underwent the ACDF surgery taking in consideration the number of levels operated and the classification of NDI score made by Vernon and Mior [8]. The results showed that AROM decreased as the number of levels operated increased and also that the disability increased as AROM decreased. In this work a similar analysis was not possible due to the low number of patients present in each sub-group and so only descriptive statistics were reported. When the patients were divided by the type of surgery (Table 3 and Table 4), a trend quite similar to the results of Bell et al. could be seen. Infact "only arthrodesis at one level" sub-group showed a higher ROM on the main axis for both the axial rotation and the lateral bending but the three sub-groups experienced a similar disability. ROM on the main axis in the others two sub-groups was similar for both the axial rotation and the lateral bending. When the patients were divided by the level of disability (Table 5 and Table 6), those in the severe and complete disabilty categories according to the NDI score, showed a lower ROM on main axis for both the axial rotation and the lateral bending. The patients with a NDI score less than 25 points showed a higher ROM on the main axis for both the axial rotation and the lateral bending compared those who scored more than 25 points. However, also different trends with the results of Bell et al. were observed. Infact the mild disability sub-group had a higher ROMy for the axial rotation and a higher ROMz for the lateral bending than the no disability sub-group. The moderate disability sub-group had a higher ROMz than the no

disability sub-group for the lateral bending. Looking at this data it seemed like the trend described by Bell et al. (increased disability as AROM decreased) was present only in the severe and complete disability sub-groups. Anyway statistical analyisis was not done on this data so no firm conclusions could be drawn. The mean NDI score for all patients was 11, indicating mild disability. Similarly to Bell et al., this could suggest that there is still a need for improvement of the ACDF procedure.
There are several limitations in this study. There was no cervical spine kinematic data of flexion-extension in the control group; although these data were registered for the experimental group no comparison could be performed. When the experimental group was divided in sub-groups the number of patients in each group was too low for a statistical analysis. There was no pre-operative data of the cervical spine kinematics and NDI; this meant that a comparison between the pre-operative and the post-operative situation but also between the pre-operative patients and the healthy subjects was not possible.
Despite these limitations, this is the first study which analyzed the effects of the ACDF procedure on cervical spine kinematics by not studying only ROM but also some other variables such as the Cross-correlation, the Ratio, RMSJ and STDERR which described the quality of movement.

Conclusions

This study showed that the age had an inverse correlation with ROM on the main axis for the rotation and the lateral bending. The ACDF procedure seemed to affect ROM on the main axis in both the horizontal and frontal planes. It also seemed to have a negative effect on the quality of movements but not on the coupling pattern. No significant correlation was found between NDI score, the age and the cervical spine kinematics.

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Addendum 1

Literature research

PubMED was used to search articles.

The literature research was organized choosing three big topics which were correlated to the subject of this paper:

1. the relation between disability and ROM in patients undergoing cervical spine surgey.
2. the ACDF procedure, particularly the Smith and Robinson procedure.
3. the Flock of Birds device.

1. To find articles about cervical ROM/kinematic, disability and neck surgery the following MeSH terms were combined: *disability evalutation, neck pain, surgery [subheading], range of Motion-articular* in different ways:

- *disability evalutation* AND *neck pain* AND *range of Motion, articular*
- *disability evalutation* AND *neck pain* AND *surgery*
- *range of Motion, articular* AND *neck pain* AND *surgery*

In addition, also these free terms were combined: *NDI* AND *surgery* AND *cervical spine.*
A total of 184 articles were found and the selection was based on reading the title and/or abstract; 11 articles were selected.

2. To find articles about ACDF – Smith and Robinson procedure these free terms were combined: (*Smith and Robinson*) AND *surgery* AND *cervical spine*.
90 were found and only 2 were selected to describe the procedure.
Since these two articles were published in 1958 it was difficult to obtain them.
Information on the Smith & Robinson procedure was retrived via Google.

3. To find articles about the FoB device these free terms were combined: *(Flock of Birds)* AND *cervical spine.*
7 articles were traced and 4 of them were selected.
References of a previous research of the group were taken in consideration since that work is directly connect to this one.
After the research and the selection of all relevant articles the related articles were traced.
At the end a total of 29 articles were selected.

Addendum 2

The Neck Disability Index

NECK DISABILITY INDEX

This questionnaire is designed to help us better understand how your neck pain affects your ability to manage everyday-life activities. Please mark in each section the one box that applies to you, although you may consider that two of the statements in any one section relate to you. Please mark the box that **most closely** describes your present-day situation.

Section 1: Pain Intensity
- ☐ I have no neck pain at the moment.
- ☐ The pain is very mild at the moment.
- ☐ The pain is moderate at the moment.
- ☐ The pain is fairly severe at the moment.
- ☐ The pain is very severe at the moment.
- ☐ The pain is the worst imaginable at the moment.

Section 2: Personal Care
- ☐ I can look after myself normally without causing extra neck pain.
- ☐ I can look after myself normally, but it causes extra neck pain.
- ☐ It is painful to look after myself, and I am slow and careful
- ☐ I need some help but manage most of my personal care.
- ☐ I need help every day in most aspects of self -care.
- ☐ I do not get dressed. I wash with difficulty and stay in bed.

Section 3: Lifting
- ☐ I can lift heavy weights without causing extra neck pain.
- ☐ I can lift heavy weights, but it gives me extra neck pain.
- ☐ Neck pain prevents me from lifting heavy weights off the floor but I can manage if items are conveniently positioned, ie. on a table.
- ☐ Neck pain prevents me from lifting heavy weights, but I can manage light weights if they are conveniently positioned
- ☐ I can lift only very light weights.
- ☐ I cannot lift or carry anything at all.

Section 4: Work
- ☐ I can do as much work as I want.
- ☐ I can only do my usual work, but no more.
- ☐ I can do most of my usual work, but no more.
- ☐ I can't do my usual work.
- ☐ I can hardly do any work at all.
- ☐ I can't do any work at all.

Section 5: Headaches
- ☐ I have no headaches at all.
- ☐ I have slight headaches that come infrequently.
- ☐ I have moderate headaches that come infrequently.
- ☐ I have moderate headaches that come frequently.
- ☐ I have severe headaches that come frequently.
- ☐ I have headaches almost all the time.

Section 6: Concentration
- ☐ I can concentrate fully without difficulty.
- ☐ I can concentrate fully with slight difficulty.
- ☐ I have a fair degree of difficulty concentrating.
- ☐ I have a lot of difficulty concentrating.
- ☐ I have a great deal of difficulty concentrating.
- ☐ I can't concentrate at all.

Section 7: Sleeping
- ☐ I have no trouble sleeping.
- ☐ My sleep is slightly disturbed for less than 1 hour.
- ☐ My sleep is mildly disturbed for up to 1-2 hours.
- ☐ My sleep is moderately disturbed for up to 2-3 hours.
- ☐ My sleep is greatly disturbed for up to 3-5 hours.
- ☐ My sleep is completely disturbed for up to 5-7 hours.

Section 8: Driving
- ☐ I can drive my car without neck pain.
- ☐ I can drive my car with only slight neck pain.
- ☐ I can drive as long as I want with moderate neck pain.
- ☐ I can't drive as long as I want because of moderate neck pain.
- ☐ I can hardly drive at all because of severe neck pain.
- ☐ I can't drive my car at all because of neck pain.

Section 9: Reading
- ☐ I can read as much as I want with no neck pain.
- ☐ I can read as much as I want with slight neck pain.
- ☐ I can read as much as I want with moderate neck pain.
- ☐ I can't read as much as I want because of moderate neck pain.
- ☐ I can't read as much as I want because of severe neck pain.
- ☐ I can't read at all.

Section 10: Recreation
- ☐ I have no neck pain during all recreational activities.
- ☐ I have some neck pain with all recreational activities.
- ☐ I have some neck pain with a few recreational activities.
- ☐ I have neck pain with most recreational activities.
- ☐ I can hardly do recreational activities due to neck pain.
- ☐ I can't do any recreational activities due to neck pain.

Patient Name ______________________________ Date ___________

Score _________ [50]

Addendum 3

The ACDF procedure

(reference: www.spine-health.com)

The decompression and spine fusion procedure begins with either a longitudinal or transverse incision in the lower front of the neck. The underlying musculature of the neck is carefully dissected, allowing the surgeon to expose the anterior cervical spine by retracting the esophagus and trachea toward midline and the carotid artery and associated structures laterally.

Muscles and membranes overlying the anterior cervical spine are dissected as well, and retractors are placed to protect the soft tissues of the neck as the operation proceeds.

After the surgical level(s) have been confirmed by X-ray or fluoroscopy, intervertebral discs are removed at the level(s) to be decompressed. In some instances it is only necessary to remove the abnormal discs, with or without small bone spurs at their margins.

If multiple levels are to be decompressed, especially if large osteophytes are present, the surgeon may opt to remove the vertebral bodies between the evacuated disc spaces. Biting instruments of varying sizes and shapes and high speed drills are used to remove the remaining bone and disc material, creating a trough measuring 15-16 mm in width extending superiorly and inferiorly across the entire longitudinal extent of the involved portion of the cervical spinal cord.

Removal of the vertebral body(s) comprises a corpectomy.

Bone and disc are removed down to the level of the posterior longitudinal ligament (PLL), which overlies the dura directly. The spine surgeon may chose to remove the PLL if it is felt that it contributes to the compression of the spinal cord, or there are fragments of herniated disc material beneath it. In that case the posterior longitudinal ligament is then carefully grasped and incised, and then removed in a piecemeal fashion.

The spine surgeon will often use either an operating microscope or surgical loupes to provide for magnification and illumination as the operation proceeds. Although the dural sac is visualized during the decompression, the spinal cord and nerve roots are not directly seen.

After the spinal cord and nerve roots have been decompressed at the appropriate levels, the portions removed must be reconstructed so as to support the normal loads of the cervical spine. This means either inserting bone grafts within each disc space ('interbody' grafts), or inserting a longer 'strut' graft which spans the defect created in the process of removing a vertebral body(s). In either case the intent is to promote the formation of a living bridge of bone between the previously distinct vertebrae (a spine fusion). The spine surgeon may employ either the patient's own bone (autograft) or banked human cadaver bone (allograft), or an synthetic scaffold into which bone graft may be inserted (metal or carbon fiber cages). The reasons for selecting among these are many and complex. Patient and surgeon should discuss these issues pre-operatively, keeping in mind that the chosen strategy will influence the likelihood of healing success. Failure of bone graft healing is among the principal reasons for repeat surgery in these cases.

In many cases, the spine surgeon will recommend internal fixation of the operated/grafted segments with a titanium plate and screw device, which is secured to the remaining vertebral bodies at the margins of the corpectomy, providing for further stability and promoting adequate fusion as well as preventing dislodgement of the bone graft (see Figure.....). Factors thought to increase the probability of bone graft/fusion failure include: 1) increasing numbers of levels to be fused, 2) smoking or other sources of nicotine, 3) patient non-compliance with activity restriction and/or brace wear, 4) poor bone quality (osteoporosis), 5) certain medications (e.g. predisone, anti-inflammatories, chemotherapy), 6) malnutrition, etc.

The usual length of stay in the hospital for decompression and spine fusion surgery varies from one to four days.

Addendum 4

Mathcad analysis of the data

In Figure 1 a graphic of an acquisition is reported. The movement on main axis is a rotation (blue line) while coupled movements are lateral bending (green line) and flexion-extension (dotted red line). The graphic was traced and two point closest to the zero were chosen on the main axis movement line; in this case the blue line was traced (Figure 2).

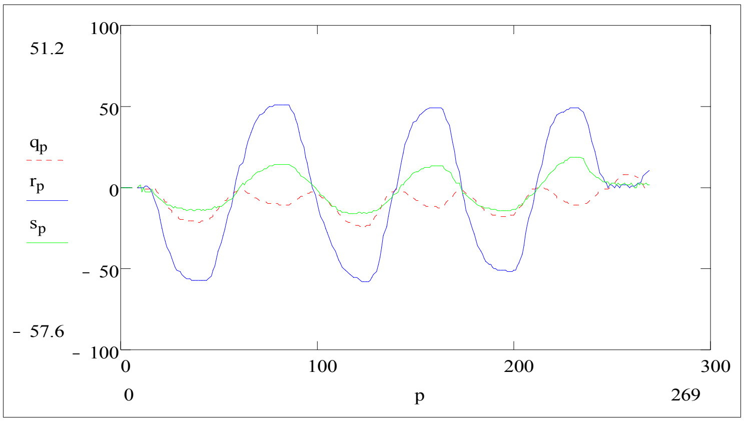


Figure 1: an example of a graphic obtained by Mathcad analysis.

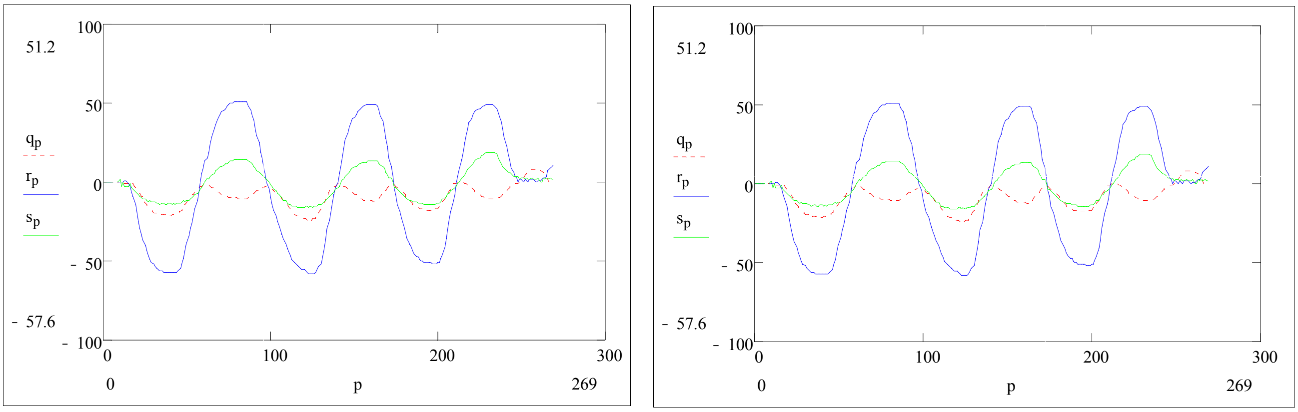
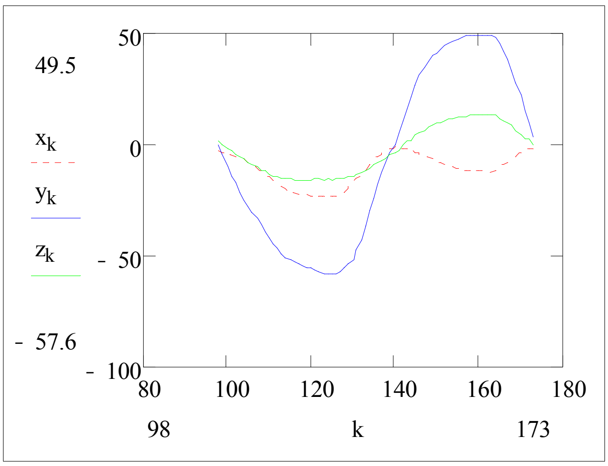


Figure 2: a selection of two points closest to zero.

This allowed to obtain one single wave for which the values of all eleven parameters were calculated (Figure 3).



Cor: 0,99
ratio: 3,706

rangex: 23,7
rangey: 107,1
rangez:29,8

stderrx: 1,839
stderry: 2,22
stderrz: 0,489

rmsjx: 1,185
rmsjy: 1,402
rmsjz: 1,191

Figure 3: a single wave obtained after tracing the graph and the values of eleven parameters.

Acknowledgement

There are several people I would like to thank....

….first of all Prof. Dr. Erik Cattrysse for his willingness despite his very busy schedule due to the incoming ISB 2011 Congress. He always found the time to answer my questions, clarify my doubts and give me many advices with a huge patience and kindness. I want to thank him and his family also for host me in their house during my internship and for the talks we had on music, beer, wine and grappa. Next time we will meet each other I'll bring you for sure one bottle of grappa from my region, Friuli Venezia Giulia.

…..all the teachers and the students of "Vrije Universiteit Brussel" for welcome me during the dissection courses. It was an amazing experience for me.

…...the "Università di Genova" and the coordinator of the "Master in riabilitazione dei disordini muscoloscheletrici" Marco Testa for the opportunity of being here in Brussels for three months.

…..all the teachers of the "Master in riabilitazione dei disordini muscoloscheletrici" because thanks to this Master I learnt so many new things which completely changed me as a physiotherapist.

….all the boys and girls I met here in the Studenthome. It was a great experience to know people from all over the world.

…..and last but not least, all my family for supporting me during this journey and being always close to me.