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Assessment of cervical range of motion in patients after axis fracture

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ABSTRACT

Background: Surgical treatment of odontoid fractures with posterior C1/C2 fusion always leads to severe limitations in mobility of the cervical spine and head.

Purpose: To assess the mobility of the cervical spine in patients treated with various surgical methods after an axis body fracture.

Material and methods: A group of 61 subjects receiving surgical treatment in a group of 214 subjects treated for odontoid fractures at one ward of neurosurgery at a regional hospital. Studies also included odontoid peg and Hangman fractures. The range of motion of the head was compared to standards by the International Standard Orthopedic Measurements (ISOM) and to head mobility in a control group of 80 healthy subjects without any pathologies or complaints associated with the cervical spine. Ranges of motion were measured with the CROM goniometre with regard to flexion, extension, right and left lateral flexion and right and left rotation. The functional status was evaluated with Neck Disability Index (NDI) standard questionnaires indicated for patients with cervical spine pain.

Results: Except for flexion and extension, patients after odontoid fractures had a statistically significantly smaller range of motion of the cervical spine in all planes compared to the control group and ISOM standards.

Conclusions: Odontoid fractures lead to limitations in mobility of the cervical spine even after treatment with methods that in theory should preserve the C1/C2 mobility.

1. Introduction

Depending on a surgical method treatment of odontoid fractures includes permanent exclusion of at least one segment of the upper cervical spine from the range of motion. As C1/C2 and C0/C1 segments are responsible for nearly half of total axial rotation, flexion and extension of the head, consequences of fusion in the upper section of the cervical spine include severe limitations in mobility of the head [1].

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These are least pronounced if the fusion selectively involves C2/C3 segment, and they are greater in the case of atlantoaxial or occipitocervical area [2]. The more distally craniospinal fusion reaches the greater reduction of the cervical spine mobility can be observed [3–6]. Based on our clinical observations, limitations in mobility of the head are present in patients operated on with selective odontoid peg fusion. It is surprising to observe because in theory this method preserves the mobility of the upper section of the cervical spine and of subaxial spine segments. Because of such observations a decision was made to review the mobility of the cervical spine more precisely in all patients receiving surgical treatment due to odontoid fractures. Another assumption to start studies is a low number of reports regarding spine mobility after odontoid fractures in literature [7–11].

2. Purpose

Objectives of the studies were as follows:

(i) evaluation of the range of motion of the cervical spine in patients receiving surgical treatment because of odontoid fractures and a comparison of these ranges to ISOM physiological standards and results from the control group including healthy subjects
(ii) evaluation of the range of motion of the cervical spine depending on a surgical technique used

3. Material and methods

3.1. *Participants*

The study group was recruited from a group of 214 subjects treated for odontoid fractures at a ward of neurosurgery at a large regional hospital in the period 2004–2012. This series of cases included 152 odontoid peg fractures, 45 Hangman fractures and 17 odontoid body fractures (Table 1). Surgical treatment was applied in the majority of these fractures, and the remaining cases received conservative treatment (Tables 2–4). The incidence of synostosis depended on the type of treatment and applied surgical technique as well as the patient's age (Tables 5–7).

61 patients from the whole group of 214 subjects were enrolled into the study regarding head mobility. They had to meet the following inclusion criteria:

1. isolated odontoid fracture without accompanying fractures in the upper and subaxial segment of the cervical spine.

Table 1 – Odontoid fractures between 2002 and 2012.

Fracture type	Number of cases
Odontoid peg	152
Hangman	45
C2 vertebral body	17
Total	214

Table 2 – Treatment of odontoid peg fractures.

Treatment modality	Number of cases
Surgical	118
Conservative	28
Spontaneous fusion without treatment (neglected cases)	3
Early in-hospital death	3
Total	152

Table 3 – Treatment of Hangman fractures.

Treatment modality	No. of cases
Total	45
Surgical (C2/C3 anterior fusion)	38
Conservative	7

Table 4 – Treatment of C2 body fractures.

Treatment modality	No of cases
Total	17
Surgical (C2/C3 anterior fusion)	5
Conservative	12

2. observed bony union of the odontoid fracture documented by a computed tomography scan.
3. minimum 2 years of follow-up.

A bony union was evaluated with bone windows of computed tomography in three reconstructions (transverse, sagittal and frontal). A bony union was confirmed when there were bony bridges in at least one of three reconstructed planes.

ll study participants had been informed about the objective of the study and had given their consent for participation before the study started. The study plan was approved by the Bioethics. The study group included 19 women and 42 men. The mean age of patients was 49.2 ± 18.3 years (18–80 years). 50.8% of patients with odontoid peg fractures were operated on with the use of a direct odontoid screw, 49.2% with posterior selective atlantoaxial fusion (Table 8).

The control group included 80 subjects (46 women and 34 men) without a clinically diagnosed disease of the cervical spine and without any complaints of this section. This group was matched to the study group with regard to the age. The mean age was 48.6 ± 17.5 years (range 19–79 years).

3.2. *Measurements*

The examination of the range of motion of the cervical spine was performed with the CROM (Cervical Range of Motion) goniometre using the SFTR protocol (measurements in the sagittal, frontal and transverse planes, and in axial rotation). Ranges of motion in the study group were compared to the ranges in the control group and to the ranges of motion of the cervical spine according to ISOM (International Standard Orthopedic Measurements). Standards were prepared by ISOM using a group of 1000 healthy subjects [7]. All measurements were performed in a sitting position, with the back supported and the head in the Frankfurt plane [11,12].

Table 5 – Bony union achieved after surgical treatment of odontoid peg fracture.

Number of patients	Bony union	Non-union	Stability at the fusion site	Unstable at the fusion site
Total (84)	90.5%	9.5%	96.5%	3.5%
Geriatric >65 yrs (19)	79%	21%	100%	0%
Odontoid screw	86%	14%	96%	4%
Odontoid screw geriatric	89%	11%	100%	0%
Posterior fusion	94%	6%	100%	0%
Posterior fusion geriatric	70%	30%	100%	0%
Posterior screws	100%	0%	100%	0%
Laminar hook/rod	82%	18%	100%	0%
Laminar hook/rod non-geriatric	93%	7%	100%	0%
Laminar hook/rod geriatric	70%	30%	100%	0%

Table 6 – Bony union achieved in conservatively managed patients with Type II and III odontoid peg fractures.

Number of patients	Bony union	Non-union	Stability at the fusion site	Unstable at the fusion site
Total (26)	85%	15%	88%	12%
Geriatric >65 yrs (3)	1 case (Type II)	2 cases (1 Type II, and 1 Type III)	2 cases	1 case

Table 7 – Bony union after treatment of Hangman fractures.

Number of patients	Bony union	Non-union	Stability at the fusion site	Unstable at the fusion site
Total 45	100%	0%	100%	0%
Surgical (C2/C3 anterior fusion)	100%	0%	100%	0%
Conservative	100%	0%	0%	0%

Table 8 – Characteristics of a group with regard to a type of a surgery.

Type of operation	Study group	
	N	%
Posterior C1/C2 fusion	30	49.2%
Direct odontoid screw	31	50.8%
Total	61	100.0%

The functional status was evaluated with Neck Disability Index (NDI) standard questionnaires indicated for patients with cervical spine pain. This scale measures the quality of physical functioning, namely the quality of life according to the patient's subjective opinion. It includes questions about ten aspects of daily functioning divided into the following areas: pain intensity, independence in everyday activities, lifting objects, reading, headache, concentration, work, driving, sleeping and recreation. In each section a subject can select one out of five responses with scores from 0 to 5 points. Based on answers to these questions it is possible to assess patient's functioning during individual daily life activities, and a score is presented on the scale between 0 and 5. The sum of points from all questionnaire sections may be between 0 and 50. Results obtained may be also presented as percentage between 0 (0 points) and 100% (50 points). The higher the total sum is the worse the quality of life and physical dysfunction are. Values belonging to 0–19% indicate no disability, 20–39% – mild disability, 40–59% – moderate disability, 60–79% – severe disability, whereas the compartment 80–100% indicates complete disability, limited motor functions causing a patient to remain in a lying position due to pain [13,14].

3.3. *Data and statistical analysis*

The statistical analysis was performed in the Statistica 10.0 software. The W Shapiro–Wilk test was used to assess whether distributions were normal, and the Levine test was used to assess homogeneity of variance. The following non-parametric tests were used in the study: Mann–Whitney test and Anova by Kruskal–Wallis. The last test was supplemented with a post hoc test (test of multiple comparisons) in cases where statistically significant correlations had been observed. The *t*-Student test was used to compare results obtained for the range of motion of the cervical spine with general standards. The comparison of the ranges of motion in the study and control groups was performed with the *Z* test. A result of a statistical test of $p < 0.05$ was assumed as statistically significant.

4. Results

Tables 9 and 10 show ranges of motion of the cervical spine in each out of six main planes. Table 9 shows a comparison of ranges of motion in the study group and physiological ranges of motion of the cervical spine according to ISOM. Table 10 shows ranges of motion in the study group compared to ranges of motion in the control group.

When ranges of motion of patients were assessed taking into account ISOM standards the greatest reduction of mobility regarded lateral flexion, axial rotation and flexion/extension, in that order. Differences between ranges of motion in the study group and ISOM standards were statistically significant in all planes except for flexion and extension. In general, ranges of motion of the cervical spine in surgical patients were

Table 9 – Comparison of physiological ranges of motion of the cervical spine according to ISOM and ranges of motion in the study group.

Range of motion [CROM]	Study group N = 61					ISOM norm	P	
	$\bar{x}$	Me	Min	Max	sd		t	p
Flexion	36.7	38.0	5.0	70.0	17.6	40	−1.46	0.1478
Extension	42.1	40.0	0.5	75.0	18.7	40	0.86	0.8610
Left lateral bending	25.2	20.0	0.0	70.0	14.4	45	−10.74	0.0000***
Right lateral bending	23.8	20.0	5.0	60.0	14.0	45	−11.86	0.0000***
Left axial rotation	38.9	38.0	5.0	90.0	19.1	50	−4.53	0.0000***
Right axial rotation	39.7	35.0	5.0	90.0	20.4	50	−3.93	0.0004***

t – result of Student's *t*-test. *p* – significance level, maximum probability of error. $\bar{x}$– arithmetic mean of range of motion expressed in degrees. sd – standard deviation.

Table 10 – Regarding ranges of motion of the spine in the study group and control group.

Range of motion [CROM]	Study group		Control group		P	
	$\bar{x}$	sd	$\bar{x}$	sd	z	p
Flexion	36.7	17.6	56.1	10.4	−6.38	0.0000
Extension	42.1	18.7	69.0	17.6	−7.03	0.0000
Left lateral bending	25.2	14.4	42.9	10.9	−6.98	0.0000
Right lateral bending	23.8	14.0	43.1	9.6	−7.39	0.0000
Left axial rotation	38.9	19.1	68.3	13.2	−7.86	0.0000
Right axial rotation	39.7	20.4	68.8	12.4	−7.56	0.0000

z – normal distribution, z test result, *p* – significance level, maximum risk probability of an error.

between 66% and 100% of the range of motion according to ISOM standards.

These differences were greater regarding ranges of motions measured in the control group. The ranges of motion in the study group were between 55% and 75% of the mobility in healthy subjects in the control group. When comparing a range of motion in the study group treated with a direct odontoid screw and ISOM standards significant differences were observed for lateral flexion. In patients operated on with posterior C1/C2 fusion differences were statistically significant in all planes except for extension (Table 11).

Table 12 shows a range of motion of the spine in degrees (median) for all treatment methods and all planes. These values were compared to ranges of motion in the control group. An asterisk indicates statistically significant differences. Table 12 shows which method had the greatest and the lowest effects on the range of motion of the cervical spine. Study groups were different only with regard to rotation. A better range of motion is observed in patients operated on with a direct odontoid screw compared to those treated with posterior C1/C2 fusion. On the other hand, surgical patients showed a significantly smaller range of motion compared to healthy subjects, irrespective of a surgical intervention used.

The NDI questionnaire was used to assess patients' functioning in the everyday life. Subjects reported the largest complaints about cervical spine pain and lack of a possibility to lift heavy objects. Patients felt discomfort when performing work activities, driving, and they also reported headache. They scored 8.3 points out of 50 possible points, on average. The mean quality of functioning expressed in percentage was 16.6%, and it indicates low limitations regarding functional skills. When analysing a correlation between the range of motion of the cervical spine and a grade of disability of subjects it was demonstrated that the range of motion of the cervical spine in each plane in CROM measurement was correlated with the NDI score. The lower the range of motion of the cervical spine was the higher the NDI score was. The greatest correlation (−0.4) was observed for lateral flexion and rotation (Table 13).

5. Discussion

With regard to current literature, a number of reports regarding the range of motion of the cervical spine in patients receiving surgical treatment after odontoid fractures is low [5–9]. Literature shows numerous reports regarding mobility of the cervical spine in pain syndromes of the spine due to degenerative diseases, but there are only few studies regarding patients treated after odontoid traumas [15–24]. It is surprising because with regard to surgical treatment of odontoid fractures it is often the objective of surgery to make the upper section of the cervical spine stiff. Except for fusion with an odontoid screw methods of surgical treatment lead to permanent and deliberate exclusion of the C1/C2 segment or even the atlanto-occipital joint and lower segments of the spine from motion. It is the price paid by a patient with an odontoid fracture for protection against C1/C2 instability and cervical myelopathy [25,26]. A direct odontoid screw is one of surgical methods that in theory should preserve C1/C2 mobility [27–32]. Similarly, lack of negative effects on the mobility of the C1/C2 segment should be in theory observed for

Table 11 – Comparison of physiological cervical ranges of motion according to ISOM and ranges of motion in the direct odontoid screw group and the posterior C1/C2 fusion group.

Range of motion [CROM]	Direct odontoid screw $N = 31$					ISOM norm	P	
	$\bar{x}$	Me	Min	Max	sd		t	p
Flexion	40.2	40.0	10.0	70.0	17.0	40	0.05	0.9583
Extension	44.5	40.0	10.0	75.0	21.0	40	1.17	0.2480
Left lateral bending	27.5	25.0	10.0	60.0	15.1	45	−6.47	0.0000
Right lateral bending	27.3	20.0	10.0	60.0	15.3	45	−6.45	0.0000
Left axial rotation	45.0	50.0	10.0	90.0	20.9	50	−1.32	0.1964
Right axial rotation	46.7	50.0	10.0	90.0	23.4	50	−0.78	0.4388
Range of motion [CROM]	**Posterior C1/C2 fusion $N = 30$**					**ISOM norm**	**P**	
	$\bar{x}$	Me	Min	Max	sd		t	p
Flexion	33.1	30.0	5.0	70.0	17.8	40	−2.12	0.0424
Extension	39.6	40.0	0.5	70.0	16.0	40	−0.13	0.8920
Left lateral bending	22.8	20.0	0.0	70.0	13.5	45	−8.98	0.0000
Right lateral bending	20.2	20.0	5.0	60.0	11.6	45	−11.67	0.0000
Left axial rotation	32.5	30.0	5.0	60.0	14.9	50	−6.42	0.0000
Right axial rotation	32.4	30.0	5.0	65.0	14.0	50	−6.86	0.0000

t – result of Student's t-test, p – significance level, maximum probability of error. $\bar{x}$– arithmetic mean of range of motion expressed in degrees. sd – standard deviation.

Table 12 – Ranges of motion in various planes depending on the type of treatment and differences compared to the control group.

Plane of motion	Type of treatment	Significance of differences between study groups: direct odontoid screw vs posterior C1/C2 fusion p	Mean range of motion in degrees $\bar{x}$		Significance of differences between study groups and control group (direct odontoid screw vs control group and posterior C1/C2 fusion vs control group) p
			Study groups	Control group	
Flexion	Direct odontoid screw	0.1039	40.2	56.1	0.0000
	Posterior C1/C2 fusion		33.1		0.0000
Extension	Direct odontoid screw	0.3659	44.5	69.0	0.0000
	posterior C1/C2 fusion		39.6		0.0000
Left lateral flexion	Direct odontoid screw	0.2563	27.5	42.9	0.0000
	posterior C1/C2 fusion		22.8		0.0000
Right lateral flexion	Direct odontoid screw	0.0690	27.3	43.1	0.0000
	posterior C1/C2 fusion		20.2		0.0000
Left rotation	Direct odontoid screw	0.0166	45.0	68.3	0.0000
	posterior C1/C2 fusion		32.5		0.0000
Right rotation	Direct odontoid screw	0.0167	46.7	68.8	0.0000
	posterior C1/C2 fusion		32.4		0.0000

p – probability level for Mann–Whitney test.

conservative treatment of C2 peg fractures where there is no surgical intervention but only long-term spinal immobilisation with an orthopaedic collar lasting for weeks or even months [32]. Our studies demonstrated that a patient might still suffer from severe limitations in mobility of the cervical spine after selective fusion with an odontoid screw.

As the standards for ranges of motion of the cervical spine present in the literature vary [33,34], we prepared a control group and measured ranges of motion of the cervical spine. It included 80 healthy subjects without a clinically diagnosed cervical spine disease, with a similar age structure. A comparison of ranges of motion of the cervical spine with regard to the ISOM standards and control group showed reduced mobility in the study group.

As expected, the greatest reduction of the range of motion of the cervical spine was observed after posterior atlantoaxial fusion. A limited range of motion was also observed after selective fusion with an odontoid screw. We use collar

Table 13 – Correlation between the range of motion of the cervical spine and the quality of functioning based on NDI.

CROM range of motion	Study group $N = 61$ NDI	
	R	p
Flexion	−0.3	0.0107
Extension	−0.3	0.0233
Left lateral flexion	−0.4	0.0005
Right lateral flexion	−0.4	0.0002
Left rotation	−0.4	0.0004
Right rotation	−0.4	0.0008

R – corelation, *p* – significance level, maximum risk probability of an error.

immobilisation after screw fusion in our patients until a bony union has been observed. Long-term immobilisation with a hard collar may lead to contractures of the ligament-bursal structures and paraspinal muscles. It may explain limitations in mobility of the cervical spine. Another explanation may include a smaller or greater damage to the ligament-bursal structures that accompanies C1/C2 dislocation. During a healing process it may become contracted, and as a result the C1/C2 segment mobility may be reduced. In such a case even selective fusion of an odontoid peg and body will not prevent limitations in mobility during a healing process. Therefore, we state that patients after odontoid fractures treated with methods to preserve segment mobility should receive rehabilitation aimed to restore the maximum range of motion of the cervical spine and head after the fracture healed.

The worst outcomes regarding head mobility were observed in patients operated on from a posterior approach. The greatest reduction was observed for axial rotation, as expected. It is well known that even up to 40% of total head rotation with regard to the trunk is in the antlantoaxial segment. Therefore elimination of rotation in this segment results in global reduction of its range [1,3].

Lateral flexion is mainly a function of the middle and lower segments of the cervical spine [3,25,26]. Therefore reduction of mobility in this plane is not as expressed as for axial rotation. Functional skills were also assessed in the study group. In 68.4% there were not any disorders associated with daily functioning. 25.3% had mild problems in this aspect, 3.8% showed moderate disability in everyday life. With regard to all activities presented in the NDI questionnaire averaged results for the whole group indicate mildly reduced functional skills in 16.6%. There was a weak negative correlation with functional skills for measurements of ranges of motion in degrees for all movements. Severe limitations in mobility of the cervical spine are associated with higher limitations in everyday functioning. Studies by Gilles et al. demonstrate that NDI reduction is associated with improvement of spinal functioning in studied patients [35].

6. Conclusions

1. Subjects after odontoid fractures treated surgically show statistically significant limitations in the range of active movements of the cervical spine compared to those without any abnormalities in the cervical spine.
2. Type of surgery affects the range of motion of the cervical spine after odontoid fractures.

Conflict of interest

None declared.

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REFERENCES

[1] Swartz E, Floyd RT, Cendoma M. Cervical spine functional anatomy and biomechanics of injury due to compressive loading. J Athl Train 2005;40(3):155–61.
[2] Koller H, Acoste F, Forstner R, Zenner J, Resch H, Tauber M, et al. C2 – fractures: Part II. A marphometrical analysis of computerized atlantoaxial motion, anatomical alignment and related clinical autcomes. Euro Spine J 2009;18(8):1135–53.
[3] Radek A, Maciejczak A. Stabilizacja kręgosłupa cz. I. Kręgosłup szyjny. Wydawnictwo AGH Kraków 2006;36–8.
[4] Cunningham BW, Hu N, Zorn CM, McAfee PC. Biomechanical comparison of single- and two-level cervical arthroplasty versus arthrodesis: effect on adjacent-level spinal kinematics. Spine J 2010;10(4):341–9.
[5] Anderson PA, Sasso RC, Hipp J, Norvell DC, Raich A, Hashimoto R. Kinematics of the cervical adjacent segments after disc arthroplasty compared with anterior discectomy and fusion: a systematic review and meta-analysis. Spine (Phila Pa 1976) 2012;37(22):85–95.
[6] Kelly MP, Mok JM, Frisch RF, Tay BK. Adjacent segment motion after anterior cervical discectomy and fusion versus Prodisc-c cervical total disk arthroplasty: analysis from a randomized, controlled trial. Spine (Phila Pa 1976) 2011;36(15):1171–9.
[7] Hu Y, Dong WX, Kepler CK, Yuan ZS, Sun XY, Zhang J, et al. A novel anterior odontoid screw plate for C1–C3 internal fixation: an in vitro biomechanical study. Spine (Phila Pa 1976) 2016;41(2):64–72.
[8] Hu Y, Yuan ZS, Kepler CK, Albert MT, Xie H, Yuan JB, et al. Deviation analysis of atlantoaxial pedicle screws assisted by a drill template. Orthopedics 2014;37(5):420–7.
[9] Muthukumar N. C1–C3 lateral mass fusion for type IIa and type III Hangman's fracture. J Craniovertebr Junction Spine 2012;3(2):62–6.
[10] Guo Q, Zhang M, Wang L, Lu X, Guo X, Ni B. Comparison of atlantoaxial rotation and functional outcomes of two non-fusion techniques in the treatment of Anderson-D'Alonzo type II odontoid fractures. Spine (Phila Pa 1976) 2015;10.
[11] Song KJ, Lee KB, Kim KN. Treatment of odontoid fractures with single anterior screw fixation. J Clin Neurosci 2007;14(9):824–30.
[12] Kilar JZ, Lizis P. Leczenie ruchem. Badanie narządu ruchu w rehabilitacji. Kraków 1996;39–40.
[13] Carreon LY, Glassman SD, Campbell MJ, Anderson PA. Neck Disability Index, short form-36 physical component summary, and pain scales for neck and arm pain: the

minimum clinically important difference and substantial clinical benefit after cervical spine fusion. Spine J 2010;10:469–74.
[14] Swanenburg J, Humphreys K, Langenfeld A, Brunner F, Wirth B. Validity and reliability of a German version of the Neck Disability Index (NDI-G). Man Ther 2014;19:52–8.
[15] Zembaty A, Kinezyterapia T1. Zarys podstaw teoretycznych i diagnostyka kinezyterapii. Wydawnictwo ''Kasper'' Sp. z.o.o.; 2003. p. 68–126.
[16] Walasik M, Gałęcki S, Dudkiewicz Z. Zastosowanie wybranych technik terapii manualnej według Mulligan koncept u pacjentów z dolegliwościami bólowymi odcinka szyjnego kręgosłupa. Kwart Ortop 2013;3:282–92.
[17] Sipko T, Bieć E, Demczuk-Włodarczyk E, Ciesielska B. Ruchomość kręgosłupa w odcinku szyjnym oraz równowaga ciała u osób z chorobą przeciążeniową kręgosłupa. Ortopedia Traumatol Rehabil 2007;2(6):141–8. Vol. 9.
[18] Chiu TT, Sing KL. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. Clin Rehabil 2002;16(8):851–8.
[19] Castro WH, Sautmann A, Schilgen M, Sautmann M. Noninvasive three-dimensional analysis of cervical spine motion in normal subjects in relation to age and sex. An experimental examination. Spine (Phila Pa 1976) 2000;25 (4):443–9.
[20] Youdas JW, Garrett TR, Suman VJ, Bogard CL, Hallman HO, Carey JR. Normal range of motion of the cervical spine: an initial goniometric study. Phys Ther 1992;72(11):770–80.
[21] Cagnie B, Cools A, De Loose V, Cambier D, Danneels L. Reliability and normative database of the Zebris cervical range-of-motion system in healthy controls with preliminary validation in a group of patients with neck pain. J Manipulat Physiol Ther 2007;30(6). 450-405.
[22] Jasiak-Tyrkalska B, Frańczuk B. Sprawność ruchowa kręgosłupa szyjnego w zespole bólowym niestabilności szyjnego odcinka kręgosłupa. Przegląd Lekarski 1999;56 (2):148–51.
[23] Cattrysse E1, Moens M, Schaillée E, D'Haens J, Van Roy P. Changed cervical kinematics after fusion surgery. Eur Spine J 2012;21(7):1353–9.
[24] Assink N, Bergman GJD, Knoester B, Winters JC, Dijkstra PU, Postema K. Interobserver reliability of neck-mobility measurement by means of the flock-of-birds electromagnetic tracking system. J Manipulat Physiol Ther 2005;28(6):408–13.
[25] Maciejczak A, Radek A. Stailizacja pogranicza czaszkowo – kręgosłupowego śrubami. Neur Neurochir Pol 1999; T.33:1403–13.
[26] Maciejczak A, Radek A. Techniki stabilizacji kręgosłupa szyjnego. Postępy Medycyny Klinicznej I Wojskowej 2001; (6):1–8.
[27] Reynolds J, MacDonald JD. Direct C2 pedicle screw fixation for axis body fracture. World Neurosurg 2016;17(16):30432–6.
[28] Godlewski B, Radek M, Radek A. Nietypowy sposób jednoczasowej gry pozycji złamania zęba obrotnika z dostępu przez tylną ścianę gardła oraz bezpośredniego zespolenia złamania śrubą dociskową z dostępu podżuchwowego. Ortoped Traumatol Rehabil 2009;1(6):61–7. Vol. 11.
[29] Takai H, Konstantinidis L, Schmal H, Helwig P, Knöller S, Südkamp N, et al. Oblique axis body fracture: an unstable subtype of Anderson type III odontoid fractures-apropos of two cases. Case Rep Orthop 2016;7561682.
[30] Stein G, Meyer C, Marlow L, Christ H, Müller LP, Isenberg J, et al. Type 2 dens fracture in the elderly and therapy-linked mortality: conservative or operative treatment. Unfallchirurg 2015;14–8.
[31] Frobin W, Leivseth G, Biggemann M, Brinckmann P. Sagittal plane segmental motion of the cervical spine. A new precision measurement protocol and normal motion data of healthy adults. Clin Biomech (Bristol Avon) 2000;17(1):21–31.
[32] Stulík J, Vyskocil T, Sebesta P, Kryl J. Combined atlantoaxial fractures. Acta Chir Orthop Traumatol Cech 2005;72(2):105–10.
[33] Frobin W, Leivseth G, Biggemann M, Brinckmann P. Sagittal plane segmental motion of the cervical spine. A new precision measurement protocol and normal motion data of healthy adults. Clin Biomech (Bristol Avon) 2002;17(1):21–31.
[34] Vaccaro AR, Kepler CK, Kopjar B, Chapman J, Shaffrey C, Arnold P, et al. Functional and quality-of-life outcomes in geriatric patients with type-II dens fracture. J Bone Joint Surg Am 2013;95(8):729–35.
[35] Glies, Lynton GF, Muller R. Chronic spinal pain: a randomized clinical trial comparing medication, acupuncture and spinal manipulation. Spine 2003;28 (14):1490–502.