L. C. G. Persson
U. Moritz
L. Brandt
C.-A. Carlsson

Cervical radiculopathy: pain, muscle weakness and sensory loss in patients with cervical radiculopathy treated with surgery, physiotherapy or cervical collar

A prospective, controlled study

Received: 14 October 1996
Revised: 11 January 1997
Accepted: 28 January 1997

L. C. G. Persson (✉) · L. Brandt
C.-A. Carlsson
Department of Neurosurgery,
University Hospital,
S-22185 Lund, Sweden
Tel. +46-46-172426; Fax +46-46-171276

U. Moritz
Department of Physical Therapy,
University Hospital, Lund, Sweden

Abstract This prospective, randomised study compares the efficacy of surgery, physiotherapy and cervical collar with respect to pain, motor weakness and sensory loss in 81 patients with long-lasting cervical radiculopathy corresponding to a nerve root that was significantly compressed by spondylotic encroachment, with or without an additional bulging disk, as verified by MRI or CT-myelography. Pain intensity was registered on a visual analogue scale (VAS), muscle strength was measured by a hand-held dynamometer, Vigorometer and pinchometer. Sensory loss and paraesthesia were recorded. The measurements were performed before treatment (control 1), 4 months after the start of treatment (control 2) and after a further 12 months (control 3). A healthy control group was used for comparison and to test the reliability of the muscle-strength measurements. The study found that before start of treatment the groups were uniform with respect to pain, motor weakness and sensory loss. At control 2 the surgery group reported less pain, less sensory loss and had better muscle strength, measured as the ratio of the affected side to the non-affected side, compared to the two conservative treatment groups. After a further year (control 3), there were no differences in pain intensity, sensory loss or paraesthesia between the groups. An improvement in muscle strengths, measured as the ratio of the affected to the non-affected side, was seen in the surgery group compared to the physiotherapy group in wrist extension, elbow extension, shoulder abduction and internal rotation, but there were no differences in the ratios between the collar group and the other treatment groups. With respect to absolute muscle strength of the affected sides, there were no differences at control 1. At control 2, the surgery group performed somewhat better than the two other groups but at control 3 there were no differences between the groups. We conclude that pain intensity, muscle weakness and sensory loss can be expected to improve within a few months after surgery, while slow improvement with conservative treatments and recurrent symptoms in the surgery group make the 1-year results about equal.

Key words Anterior cervical fusion · Cervical collar · Cervical radicular pain · Muscle strength · Physiotherapy

Introduction

Neck pain and cervical radiculopathy is a common spinal disease after the age of 40, but there are many controversies as to the choice of treatment: whether, for instance, methods of surgical decompression and stabilization are preferable to various conservative regimens [41]. Many causes of radiculopathy may be found such as impingement from disk herniations, osteophytes and loss of disk height. Pain, muscular weakness, numbness or paraesthesias in the arms and fingers are common symptoms [17, 54]. Radiculopathy caused by a significant nerve root compression should be expected to produce weakness in the muscle innervated by the involved nerve root [25]. The clinical signs and symptoms are used to settle the diagnosis and to localize the level of cervical pathology. However, radiating pain from the neck is not exclusively an expression of nerve root compression. Muscular pain and connective tissue pathology may induce referred pain, obscuring the clinical picture [23, 54, 58]. The natural course of the cervico-brachial pain is not always predictable. In many patients pain and other radicular symptoms are spontaneously of a transient nature [20]. Furthermore, new or recurrent symptoms can arise after surgery [36, 49].

Motor or sensory loss may not always indicate the true level of pathology because of overlap or intersegmental connection of cervical roots or due to anastomoses between peripheral nerves [6, 16, 19, 22, 39, 53]. Sometimes, the patients are not aware of any motor weakness [22].

Different modalities of physiotherapy are often applied in the acute as well as the chronic phase [17, 19, 25, 56]. Many authors advocate a soft or semi-rigid collar [5, 44], while some suggest early mobilization as being most important for the relief of neck pain [35]. There are several studies demonstrating good surgical results in patients with cervical nerve root compression [14, 26, 30]. However, most studies are either personal series or uncontrolled in other respects.

In a previous study we evaluated pain intensity visual analogue scale, function (measured by the Sickness Impact Profile) and mood (measured by the Mood Adjective Check List) in patients with cervical radicular pain [47]. To our knowledge, there is so far no prospective, controlled study in which surgery is compared with conservative treatments regarding motor weakness and sensory loss in patients with cervical radiculopathy. The aim of this study was therefore to evaluate pain, muscular weakness and sensory loss in patients with long-lasting cervico-brachial pain considered to be caused by nerve root compression according to the clinical picture and MRI and to compare the effects of three randomized treatments: surgical decompression, physiotherapy and immobilization in a cervical collar in a 1-year follow-up.

Materials and methods

Patients

The study included 81 consecutive patients of both sexes, with cervico-brachial pain of more than 3 months' duration. Thirty-seven (46%) were women and 44 (54%) were men. The mean age was 47.5 years (SD 7.9) and ranged from 28 to 64 years. The patients had been referred to the out-patient clinic at the Department of Neurosurgery, University Hospital of Lund, because of neck/shoulder/arm pain, for consideration of surgical treatment. Plain radiographs and MR tomography of the cervical spine or cervical CT-myelography had been performed. The patients underwent a full neurological examination by a senior neurosurgeon (C-A.C.). Reflex disturbances, motor and sensory deficits, together with the distribution of pain were evaluated to determine the clinical level of radiculopathy.

Inclusion criteria

Pateints were included if they showed clinical and radiological signs that indicated nerve root compression corresponding to the distribution of pain but without spinal cord compression.

Exclusion criteria

Patients with spinal cord compression, whiplash, other traumatic injuries and serious associated somatic or psychiatric diseases were excluded.

Social and demographic data of the groups were recorded by comprehensive history and by a questionnaire (Table 1). The patients were given written information about the study, which had been accepted by the Ethics Committee of Lund University. They were randomized by the use of sealed envelopes into three treatment groups: surgery, physiotherapy and cervical collar.

Control group

Thirty healthy subjects were recruited from the hospital staff as a sex- and age-matched control group. None of these subjects had any history of neck pain or major injury affecting the upper limbs. The healthy subjects were tested on two occasions with 7–14 days in between. There was a significant correlation ($r = 0.66$–0.97) in muscular strength between the two test occasions, which indicates the intra-reliability of the test method. In the control group the dominant side was about 5% stronger than the non-dominant side (Table 2).

Study design

The clinical evaluation was made before treatment (control 1), and repeated at the same time of the day 14–16 weeks after surgery or after the start of the conservative treatments (control 2), and after a further 12 months (control 3). Control 3 always took place at the predetermined time, even if the patients were reoperated between control 2 and 3. The clinical evaluation was done by a physiotherapist (L.P.) according to a fixed protocol with emphasis on the neurological and musculoskeletal examination. The same physiotherapist performed all three examinations, but did not take part in the physiotherapy treatment.

The clinical trials were carried out according to the "intention to treat" principle [2]. Three patients, randomized to the surgical group, rejected surgery because of spontaneous improvement at the time of operation, but the allocation to the surgical group was

Table 1 Characteristics of the 81 patients by treatment group and of the 30 control subjects

	Group							
	Surgery (n = 27)		Physiotherapy (n = 27)		Cervical collar (n = 27)		Control (n = 30)	
Men (%)	16	(59)	11	(41)	17	(63)	18	(60)
Women (%)	11	(41)	16	(59)	10	(37)	12	(40)
Height (cm)	173	± 10	171	± 9	172	± 7	175	± 8.9
Weight (kg)	74	± 13	75	± 15	76	± 12	75	± 13
Age at examination (years)								
Mean (median)	45	(47)	48	(48)	49	(50)	46	(46)
SD		± 8.5		± 8.1		± 8.5		± 9.7
Range	28	–58	31	–61	38	–64	28	–64
Age at pain onset (years)								
Mean (median)	42	(43)	44	(45)	47	(49)		
SD		± 8.4		± 7.4		± 6.6		
Range	20	–56	28	–58	36	–63		
Pain duration (months)								
Mean (median)	34	(15)	40	(31)	28	(21)		
SD		± 34.8		± 32.5		± 24.3		
Range	5	–120	6	–120	8	–120		
Affected side (control 1)								
Right (%)	12	(44)	15	(55)			14	(49)
Left (%)	15	(55)	12	(44)			13	(51)
Dominant side								
Right (%)	24	(89)	27	(100)			24	(89)
Left (%)	3	(11)	0	(0)			3	(11)
Earlier treatment								
Physiotherapy (%)	26	(96)	22	(81)			21	(77)
Cervical collar (%)	11	(41)	13	(54)			10	(37)
Affected level[a]								
C3-C4 (%)	1	(4)	0	(0)			0	(0)
C4-C5 (%)	2	(7)	4	(15)			2	(7)
C5-C6 (%)	13	(48)	12	(44)			15	(56)
C6-C7 (%)	10	(37)	10	(10)			10	(37)
C7-C8 (%)	0	(0)	1	(4)			0	(0)
C8-T1 (%)	1	(4)	0	(0)			0	(0)
Sick leave (months)	(n = 23)		(n = 18)				(n = 21)	
Mean (median)	13	(10)	15	(13)			13	(9)
SD		± 9.6		± 10.3				± 13.0
Range	1	–45	6	–40			0	–50

[a] The worst affected level based on MRI records

retained. In the physiotherapy and cervical collar groups, all patients carried out the allocated treatment. No other treatments were given between control 1 and 2. Between control 2 and 3 some patients received treatments other than those determined by the randomization. In the surgery group, eight patients had a second operation, six on levels adjacent to the originally operated disc, one because of an infected bone graft, and one underwent a plexus exploration. Eleven individuals in the surgery group received physiotherapy. One patient in the physiotherapy group and five patients in the collar group were operated upon using the Cloward technique. Twelve patients in the collar group received physiotherapy.

Drop-outs

At control 3 one patient in the surgery group had moved and was not examined and one patient in the collar group did not keep the appointment because she had completely recovered.

Measurements

Pain intensity was assessed by means of a visual analogue scale (VAS) [32]. Current pain and the worst pain during the previous week had to be filled in on two different scales. Pain intensity assessment forms were sent together with the appointment for the clinical examination. Patients were asked to fill in the form and to

Table 2 Differences in muscle strength between the affected side and non-affected side in patients before treatment (control 1) and in the control group (muscle strengths measured in kilograms, hand grip in kilopascals)

Variables	Right-side affected ($n = 41$)			Left-side affected ($n = 40$)			Control group ($n = 30$)		
	Right side Mean (± SD)	Difference *P*-level	Left side Mean (± SD)	Right side Mean (± SD)	Difference *P*-level	Left side Mean (± SD)	Right side Mean (± SD)	Difference *P*-level	Left side Mean (± SD)
Pinch grip	2.09 (1.03)	***	2.43 (0.98)	2.29 (0.81)	***	1.93 (0.87)	3.30 (0.63)		3.24 (0.64)
Hand grip	77 (0.32)	***	94 (0.26)	87 (0.31)	**	74 (0.34)	126 (0.25)		127 (0.27)
Wrist extensors	15.3 (5.43)	***	17.7 (4.82)	16.7 (4.76)	ns	15.5 (5.50)	24.6 (4.04)		25.4 (5.30)
Wrist flexors	16.2 (5.99)	**	17.9 (5.35)	17.8 (5.27)	**	15.9 (5.88)	26.0 (4.98)		25.4 (5.29)
Elbow extensors	14.1 (5.86)	***	17.2 (5.67)	15.2 (4.96)	***	13.1 (5.63)	20.0 (4.78)	*	19.1 (4.37)
Elbow flexors	17.5 (7.49)	***	22.4 (4.87)	20.1 (7.06)	ns	19.7 (7.03)	29.6 (5.32)	*	28.6 (5.07)
Shoulder abductors	15.6 (6.20)	*	16.9 (5.47)	16.9 (6.76)	***	14.2 (5.65)	25.4 (6.39)		24.6 (6.09)
Shoulder adductors	18.7 (6.60)	ns	20.1 (5.83)	19.9 (7.70)	***	17.4 (7.37)	30.6 (6.17)	*	29.8 (6.76)
Shoulder elevator	19.5 (7.66)	**	21.7 (6.77)	21.0 (7.69)	***	18.2 (7.33)	31.1 (6.39)	*	28.7 (8.74)
Shoulder extensors	19.8 (8.19)	***	22.5 (6.65)	20.8 (8.02)	**	19.0 (7.90)	31.9 (7.13)		31.6 (7.18)
Shoulder internal rotators	13.6 (5.09)	***	16.0 (4.60)	14.7 (4.89)	**	12.8 (4.64)	23.3 (5.07)	*	20.2 (4.22)
Shoulder external rotators	11.7 (4.43)	**	13.2 (3.99)	12.4 (4.95)	***	10.7 (4.37)	15.9 (4.32)		15.4 (4.13)

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

bring it to the appointment. The pain intensity assessment was repeated at the appointment 8–12 days after the patients had received the forms by mail. (Reproducibility coefficients for current pain and worst pain were at control 1 $r = 0.82$ and 0.60, control 2 $r = 0.82$ and 0.66 and control 3 $r = 0.78$ and 0.87). Mean current pain intensity and mean worst pain during the previous week were used for statistical analysis.

Muscular strength in the upper limb was measured in patients and controls by means of a hand-held spring dynamometer (Svantometer, Lund, Sweden) giving the results in kilograms (1 kg = 10 N). Maximal isometric breaking force was measured for elbow flexors, elbow extensors, shoulder abductors, shoulder adductors, shoulder rotators, shoulder flexors, shoulder extensors, wrist flexors and wrist extensors. All measurements were performed by one experienced physiotherapist (L.P.) using a standardized protocol and standardized test positions. Patients and controls were instructed to pull or push maximally against the force of the dynamometer for 3–5 s up to breaking point. Before testing each muscle group, the test was demonstrated to the patient in detail. The measurements were made in the same order, starting with the non-affected side. Each muscle group was tested twice, with 20–30 s of rest in between (reproducibility coefficients, $r = 0.96$–0.99). The score was recorded to the nearest kilogram and the best value was used for the statistical analysis. The ratio of the affected to the non-affected side was calculated. The results of the muscle group measurements are described in Table 2.

Hand-grip strength was measured with a Martin Vigorometer (Gebrüder Martin, Tuttlingen, Germany). The dynamometer consists of a rubber ball connected by a rubber tube to a manometer. The manometer scale records in kilopascals. Two ball sizes were available: large (60 mm in diameter) for the men, and medium (47 mm in diameter) for the women. The tests were performed with the patient sitting in a chair with the arm adducted in a neutral position and the elbow resting on the chair arm at 90° of flexion and the wrist free in a neutral or a slight dorsiflexion position. The patients and controls were asked to squeeze the ball maximally for some seconds. The test was performed twice, alternating between the hands. Both scores were used for test-retest evaluation and the the highest values were chosen for statistical analysis. The ratio of the affected to the non-affected hand was calculated.

The pinch strength between index finger and thumb in opposition was measured with a Mannerfelt Intrinsicmeter (Metron, Stockholm, Sweden). The tests were performed with patients sitting with the arm neutrally adducted, the elbow at 90° of flexion and the wrist in neutral position, resting on a table in front of the patient. The patients and controls were asked to put maximal pressure on the intrinsic meter. The tests were performed twice, alternating between the hands. The best values were chosen for statistical analysis. The ratio of the affected to the non-affected hand was calculated.

Sensibility in the upper extremity was evaluated with a wad of cotton wool. Both sides were tested synchronously. The extent of reduced sensation was recorded on an anatomical figure by the examiner and graded as normal, reduced or lost. For statistical analysis the course of events between control 1, 2 and 3 were classified as improved, unchanged or worse.

Sensations of numbness or tingling were noted by the patients on their own anatomical figure (anterior and posterior), which was also used to record their pain [46]. Information on frequency and trigger factors was obtained from the questionnaire and from patient's histories. For statistical analysis, data from the coded pain maps and the questionnaire items on sensation and numbness were used to calculate the course of events between the controls with respect to distribution and frequency, and patients were classified as improved, unchanged or worse.

Treatments

The surgery was performed by eight neurosurgeons according to the anterior cervical discectomy technique described by Cloward [15]. The fragments of the protruded disk and the osteophytes were removed and a bone graft from purified cow bone was used for fusion. One of the patients underwent a laminectomy by a posterior approach technique [29]. The patients were mobilized on the 1st postoperative day. A cervical collar was sometimes used postoperatively for 1–2 days. No physiotherapeutic treatment was given between control 1 and 2.

The physical therapy was provided by physiotherapists working in the patient's geographical neighbourhood. They all had documented experience with neck/shoulder/arm pain patients. The

Table 3 Number of patients and types of physical treatment modalities in the 27 patients randomized to physical therapy

Treatment modality	No. of patients
Manual cervical traction	19
Ergonomics education	18
Strengthening exercises for arm, shoulder and back	15
Isometric strengthening exercises for the neck	14
Relaxation exercises	14
Stretching exercises for the neck muscles	14
Home exercises	13
Mobilization	11
Body awareness exercises (Feldenkrais, body awareness)	9
Massage	9
Superficial heat (hot moist-packs)	9
Balance and coordination exercises	8
Deep heat (ultrasound)	8
Transcutaneous electrical stimulation (TNS)	6
Neckpillow	2
Workplace evaluation	2
Cryotherapy	1

treatments were given on 15 occasions, each of 30–45 min duration, during a 3-month period. The type of therapy was decided by the physiotherapist according to the patient's symptoms and individual preferences. Information about clinical, radiographic and MRI findings was given to the treating physiotherapists by phone or letter. Treatment procedures were recorded and returned to the Department of Neurosurgery (Table 3). Neither chiropractic manipulation nor acupuncture was used.

In the cervical collar group, several different collars were used. Rigid collars were always shoulder resting and intended to be used during day time only (Lundakrage, Miami J collar, Necky, Orthocollar, Philadelphia collar). A soft collar to be used during the night was supplied if wanted (Adams, Camp-19, Necky). Patients were instructed to wear the collar over a 3-month period. If they had any difficulties with the collar another type was provided ($n = 2$).

Statistical methods

Non-parametric tests were chosen. For inter-group comparisons a Kruskal-Wallis one-way analysis of variance was used. If the result was significant, a pairwise comparison with Mann-Whitney U-test was performed. For comparison within groups before and after treatment the Wilcoxon matched-pairs signed-ranks test and Chi-square test were used. Correlations between variables were analysed with the Spearman rank correlation coefficients. An adjustment for multiple comparisons of the strength value was done with the Bonferoni test [1]. A difference of $P < 0.05$ was considered statistically significant.

Results

To compare the three treatment groups, differences in pain, muscle strength, sensation and sensory loss between and within groups will be described.

Pain

In the series of patients there were 40 left- and 41 right-sided pain syndromes. The average current pain rating on the VAS was 49 (median 51, range 0–97) and worst pain during the previous week was 70 (median 71, range 20–100). The pain score in the different treatment groups before treatment is shown in Table 4. There was no significant difference before treatment (control 1) with regard to mean current pain or mean worst pain in the previous week.

At control 2, 4 months after the start of the treatment programmes, there was an improvement in the surgery group and the physiotherapy group regarding worst pain during the previous week, and a significant difference was seen between the surgery group and the collar group. Mean current pain was significantly higher in the cervical collar group than in the surgery and physiotherapy groups. In the within-groups comparison, mean current pain had improved only within the surgery group (Table 4).

One year later (control 3) there was no statistically significant difference between the three groups with respect to pain.

Table 4 Pain intensity within the different treatment groups at control 1 (before treatment), control 2 (after 4 months) and control 3 (after 16 months) presented as mean, median and SD of visual analogue scale values (in millimetres)

	Control 1 Mean (median) ± SD	(Diff. 1–2) *P*-level	Control 2 Mean (median) ± SD	(Diff. 2–3) *P*-level	Control 3 Mean (median) ± SD	(Diff 1–3) *P*-level
Surgery group						
Mean current pain	47 (54) 25.5	***	27 (28) 23.0	ns	30 (25) 28.1	*
Mean worst pain	72 (74) 21.3	***	43 (37) 36.1	ns	42 (28.5) 48	***
Physiotherapy group						
Mean current pain	50 (50) 20.7	ns	41 (42) 28.6	ns	39 (37) 25.8	ns
Mean worst pain	70 (68) 18.4	***	51 (61) 29.2	ns	53 (51) 28.6	**
Collar group						
Mean current pain	49 (51) 19.9	ns	48 (54) 23.2	**	35 (37) 23.6	*
Mean worst pain	68 (71) 16.5	ns	64 (65) 21.7	**	52 (62) 27.1	**

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 5 The ratio of the affected side to the non-affected side between the treatment groups at control 1 (before treatment)

Variables	Surgery group ($n = 27$)				Physiotherapy group ($n = 27$)				Cervical collar group ($n = 27$)			
	Mean	Median	± SD	Range	Mean	Median	± SD	Range	Mean	Median	± SD	Range
Pinch grip	0.78	0.80	0.22	0.36–1.12	0.91	0.96	0.29	0.10–1.80	0.87	0.84	0.221	0.43–1.25
Hand grip	85	87	24	40–150	84	88	25	25–140	85	86	29	24–157
Wrist extensors	0.86	0.92	0.23	0.29–1.27	0.94	0.94	0.14	0.63–1.17	0.89	0.89	0.27	0.24–1.64
Wrist flexors	0.81	0.91	0.21	0.23–1.20	0.93	0.95	0.17	0.50–1.15	0.92	0.94	0.25	0.29–1.58
Elbow extensors	0.75	0.81	0.23	0.33–1.09*	0.92	0.95	0.19	0.44–1.33	0.85	0.90	0.28	0.72–1.00
Elbow flexors	0.87	0.90	0.22	0.35–1.39	0.93	0.98	0.37	0.27–1.85	0.85	0.87	0.29	0.35–1.67
Shoulder abductors	0.85	0.88	0.20	0.50–1.27	0.92	0.94	0.24	0.47–1.54	0.86	0.88	0.25	0.42–1.50
Shoulder adductors	0.87	0.89	0.21	0.46–1.25	0.91	0.90	0.26	0.44–1.65	0.96	0.89	0.31	0.42–1.82
Shoulder elevator	0.91	0.88	0.29	0.43–2.00	0.89	0.91	0.18	0.50–1.21	0.85	0.90	0.16	0.40–1.23
Shoulder extensors	0.88	0.91	0.17	0.58–1.25	0.93	1.00	0.22	0.38–1.33	0.87	0.91	0.18	0.40–1.13
Shoulder internal rotators	0.78	0.79	0.23	0.31–1.18	0.92	0.92	0.18	0.50–1.25	0.91	0.86	0.32	0.33–1.73
Shoulder external rotators	0.88	0.89	0.20	0.43–1.25	0.91	0.94	0.16	0.50–1.14	0.86	0.89	0.24	0.40–1.33

* $P < 0.05$ (P-level adjusted for multiple comparisons of test occasions (Bonferroni))

Muscle strength

Six patients were left handed. There was no significant difference in muscular strength with respect to side dominance. Men were stronger than women ($P < 0.001$). For all patients the strength in the affected side was significantly less than in the non-affected side in almost all measured groups at control 1 (Table 2). Controls were stronger than patients in all muscle groups ($P < 0.001$). In 58 patients (72%) the strength in one or several muscle groups was more than 15% reduced in the affected side. Pain appearing during muscle testing was reported by 20% of the patients during testing of shoulder abduction and 10% during shoulder external rotation. In general, however, the correlation between muscle strength and current pain was low ($r = 0.24$–0.37). There was no significant correlation between reduction of strength and pain duration.

Between-groups comparison

When muscular strength was expressed as the ratio of the affected side to the non-affected side, there was no statistical difference before treatment (control 1) between the three treatment groups except for elbow extensors (Table 5). At control 2 (after 4 months), the surgery group had improved compared to the physiotherapy group concerning pinch grip, elbow extension and shoulder internal rotation, when measured as differences in ratios. The surgery group had also improved compared to the cervical collar group concerning wrist flexion and elbow flexion. At control 3, 1 year later, wrist extension, elbow extension and shoulder abduction and internal rotation showed a significantly higher ratio value in the surgery group than corresponding muscles in the physiotherapy group. There were no longer any differences in strength ratio of the tested muscular groups between the surgery group and the cervical collar group, nor between the physiotherapy group and the cervical collar group.

In addition to change in ratios, the effect of treatment on the absolute muscle strength was studied. When values for the absolute muscle strength on the affected side were compared, there was no difference between the treatment groups at control 1. At control 2, a significant improvement of elbow flexion was noted in the surgery group compared to the physical therapy group and of wrist flexion and elbow flexion compared to the cervical collar group. At control 3 no significant difference was seen between the groups with respect to absolute muscle strength.

Within-groups comparison

Some improvement in the affected side/non-affected side ratios was noted in the surgery and physiotherapy groups. At control 2 the surgery group had significantly strengthened pinch grip, elbow extension and flexion and shoulder rotation compared to control 1 (Table 6). At control 3 the surgery group had improved in the elbow extensors, shoulder internal rotators and adductors as compared to control 1. In the physiotherapy group hand grip had improved at control 3 compared to control 1. In the collar group no significant improvements were noted.

The absolute muscle strength values improved within all groups over time. In the surgery group at control 2, the absolute values of muscle strength in the affected sides had improved with respect to hand grip, wrist flexors, wrist extensors, elbow extensors, shoulder abductors and shoulder extensors. Between control 2 and 3 no signifi-

Table 6 Ratio of the affected side to the non-affected side within the surgery group ($n = 27$) at control 1, 2 and 3, and P-level of difference

Variables	Control 1				Control 2				Control 3			
	Mean	Median	± SD	(Diff 1–2)	Mean	Median	± SD	(Diff 2–3)	Mean	Median	± SD	(Diff1-3)
Pinch grip	0.78	0.80	0.22	**	0.90	0.95	0.14	ns	0.83	0.90	0.28	ns
Hand grip	85	87	24	ns	89	83	30	ns	89	98	28	ns
Wrist extensors	0.86	0.92	0.23	ns	0.93	0.96	0.18	ns	0.90	1.00	0.28	ns
Wrist flexors	0.81	0.91	0.21	ns	0.94	1.00	0.17	ns	0.90	1.00	0.23	ns
Elbow extensors	0.75	0.81	0.23	*	0.89	0.87	0.20	ns	0.86	0.86	0.16	*
Elbow flexors	0.87	0.90	0.21	**	1.03	0.99	0.29	ns	0.95	1.00	0.21	*
Shoulder abductors	0.85	0.88	0.20	ns	0.89	0.92	0.22	ns	0.97	1.00	0.24	*
Shoulder adductors	0.87	0.89	0.20	ns	0.84	0.89	0.22	ns	0.96	0.95	0.30	ns
Shoulder elevator	0.91	0.88	0.29	ns	0.90	0.93	0.28	ns	0.91	0.91	0.16	ns
Shoulder extensors	0.88	0.91	0.17	ns	0.97	0.96	0.23	ns	0.94	0.92	0.21	ns
Shoulder internal rotators	0.78	0.79	0.23	*	0.91	0.91	0.16	ns	0.96	0.91	0.18	**
Shoulder external rotators	0.88	0.89	0.20	ns	0.94	1.00	0.17	ns	0.90	0.86	0.23	ns

* $P < 0.05$; ** $P < 0.01$ (P-level adjusted for multiple comparisons of test occasions (Bonferroni))

Table 7 Occurrence, location and frequency of paraesthesia, and sensory loss in all patients ($n = 81$) before randomization (control 1)

	Paresthesia ($n = 79$; 98%)	Sensory loss ($n = 44$; 54%)
Location		
Right side	25	22
Left side	31	19
Bilateral	23	3
Radial fingers	15	15
Middle fingers	15	3
Ulnar fingers	29	17
Hand (whole)	15	2
Arm only	5	7
Frequency		
Constantly/several times a day	59	44
Occasionally	20	0

cant improvement was seen. When control 3 is compared with control 1 it appears that the patients had improved significantly in all muscle groups in the affected side except for the shoulder adductors, shoulder elevators, shoulder extensors and shoulder external rotations.

In the physiotherapy group, the absolute value of muscle strength of wrist extensors in the affected sides had improved at control 2. Between control 2 and control 3 an improvement was seen in the physiotherapy group in the pinch grip, hand grip, elbow extensors and shoulder elevators, and in the collar group there was an improvement in the wrist flexors, wrist extensors, elbow flexors and shoulder abductors, adductors, elevators and internal rotators.

Most patients in the two conservatively treated groups showed increased muscle strength when control 3 was compared with control 1.

Table 8A Change in paraesthesia and sensory loss after 4 months of treatment (control 2)

[a] Improvement in sensory loss was significantly greater in the surgery group than in the other two patient groups (* $P < 0.05$, Chi-square)

Group	Paraesthesia			Sensory loss		
	Improved	Unchanged	Worse	Improved	Unchanged	Worse
Surgery ($n = 27$)	14 (52%)	9 (33%)	4 (15%)	11 (41%)[a]	15 (55%)	1 (4%)
Physiotherapy ($n = 27$)	12 (45%)	14 (51%)	1 (4%)	4 (15%)	21 (78%)	2 (7%)
Cervical collar ($n = 27$)	10 (37%)	13 (48%)	4 (15%)	4 (15%)	21 (78%)	2 (8%)

Table 8B Change in paraesthesia and sensory loss 16 months after treatment (control 3)

Group	Paraesthesia			Sensory loss		
	Improved	Unchanged	Worse	Improved	Unchanged	Worse
Surgery ($n = 26$)	15 (58%)	6 (23%)	5 (19%)	7 (27%)	18 (69%)	1 (4%)
Physiotherapy ($n = 27$)	18 (67%)	6 (22%)	3 (11%)	4 (14%)	18 (67%)	5 (19%)
Cervical collar ($n = 26$)	17 (66%)	5 (19%)	4 (15%)	4 (15%)	20 (77%)	2 (8%)

Sensation and sensory loss

The prevalence of paraesthesia and numbness is described in the Table 7. Almost all patients felt numbness and about half of them (n = 44) experienced sensory loss. Comparisons between the treatment groups showed a significant improvement in sensory loss in the surgery group at control 2 (Table 8a), but at control 3 there were no significant differences between the groups (Table 8b).

Discussion

There are several studies about conservative treatment of cervical myelopathy [50], but only a few concern patients with cervical radiculopathy. In a study of 14 patients by Highland and co-workers, improved pain and neck strength after an 8-week clinical rehabilitation programme was found [31]. DePalma and Subin followed one conservatively treated group (n = 255) and one surgically treated group (n = 75) for 1 year. In the former, 29% obtained complete relief and 49% improved. In those who had surgery, 64% were rated as excellent and 21% as improved [16]. In this study, surgically treated patients improved regarding pain, muscle strength and sensory loss compared to the physiotherapy and the collar-treated groups when examined shortly after the treatment. After a further year, however, there were no significant differences between the surgically and non-surgically treated groups of patients with respect to pain and other sensory disturbances, but the surgery group retained a minor advantage concerning muscle strength. In a previous report [47] on the same patients, it was found that the patients' well-being (physical, psychological and social) measured by the Sickness Impact Profile Inventory and mood measured by the Mood Adjective Check List followed a similar pattern: while there was an improvement in the surgery group compared to the conservatively treated groups shortly after the treatments, there were no significant differences between the groups at the 1-year follow-up.

The similar courses of the three groups with respect to pain, muscle weakness, sensory loss and well-being is notable. While the surgical group showed better results immediately after the treatments (control 2) the groups were uniform after a further 12 months (control 3). This conformity per se strengthens the overall validity of the study. The muscular weakness in the affected arm usually involved many muscle groups in the same patient. It therefore seems most plausible that the muscular weakness was mainly due to inactivity caused by the pain and/or pain-induced motor inhibition at the time of the muscle tests. The conformity of the measurements of pain and muscle strength is therefore most likely governed by the pain.

No other prospective, randomized treatment study has, to our knowledge, compared surgery to conservative treatment for cervical radiculopathy with respect to motor weakness and sensory loss. The development of symptoms after the treatments can be due both to recurrent symptoms in the surgery group and the slow improvements over time in the other two groups. Similarly, some authors have reported late deterioration after a period of improvement in the early post-operative course [36, 53, 60]. Lunsford et al. considered that there is sometimes a need for some form of conservative treatment during the post-operative period [36].

Our patients had suffered their symptoms for more than 3 months. The most common cause of pain in our patients is compression from hard disks or osteophytes. In contrast, the acute cervical syndromes with sometimes intractable radicular pain are usally caused by herniation of a soft disk. Surgery in such syndromes of sudden onset gives very good results. Evidently, long-standing syndromes present more difficult treatment problems and the response to conservative treatment is more likely to be effective. Some authors have found that compression of normal nerves leads to paraesthesias, sensory deficits and motor loss, but not to pain. Pain occurs if an inflamed nerve is compressed [24]. Pain associated with root compression in patients with disk herniation or spinal degeneration is considered to be caused by a combination of mechanical, biochemical and metabolic irritation, leading to electrophysiologic and microcirculation changes with ischaemia, intraneural oedema and demyelination [51, 52]. Patients with long-standing root compression may not consider radicular pain as a significant symptom and the patients may instead complain of muscle weakness and sensory loss, depending on the duration of root compression [27].

Whether a cervical collar provides a reduction of mechanical stress on the nerve roots is questionable [33]. In our study, several of the patients in the collar group improved. Naylor and Mulley found that about 75% of emergency out-patients experienced a reduction in pain and paraesthesia by wearing a collar [43]. Paraesthesia was the symptom that did not differ between the groups at control 2. Paresthesia and numbness are symptoms that can occur as a consequence of pure mechanical root compression without inflammatory irritation at the spinal root [51, 52].

Quantification of muscle strength is one method to evaluate the patients' functional ability and response to treatment. Muscular weakness may be caused by nerve root involvement, but also by pain, lack of motivation and mood disturbance, or secondary muscular inactivity because of long-lasting pain. Sensory loss in the cervical root dermatomes can be another explanation for patients feeling weakness.

Few of the clinical tests for musculoskeletal disorders in the neck/shoulder have been tested for validity and reliability [59]. Measurements of maximal isometric strength in the upper limb have mostly been used as diagnostic tools, but have not been correlated to existing neck

symptoms or used as an outcome measurement for treatment. Hand-held dynamometer testing is well documented and is a reliable tool both for intra- and inter-testing [1, 9, 10, 48]. The vigorimeter and Mannerfelt Intrinsicmeter have also been shown to be reliable [18, 38]. High intrareliability of muscle strength measurements was seen in our control group. Three types of pinch may be measured [8]. In our study the pinch was performed with thumb tip to the tip of the index finger. Arm position is important and a standard position is required for score comparisons [37, 55]. For the statistical analysis we chose the best value of two scores. Hamilton et al. did not find any difference between using the mean values or the best value to determine the grip strength score [28]. The interindividual differences of muscular strength are wide even in healthy people and differ depending on sex, age, height and weight [3, 34, 42]. Pain condition on the day of testing may also play an important role. Differences between sexes were seen also in our study. In the physiotherapy group there were slightly more women than in the other two groups. In women, strength is about 65% that of men [42], and in older persons it is between 66% and 93% of that in younger people [42]. Such differences can also be seen in the strength of hand grip [4, 18, 44, 57]. In our study the patients were their own references and the difference in values were used for statistical comparisons.

We have not taken into consideration differences between the dominant and the non-dominant side (six patients were left-side dominant). The dominant side is on average 7% stronger in hand grip, with little variation with age and sex [57]. In the shoulder no such difference could be shown [42]. In our control group the differences in muscle strength between the dominant and the non-dominant side were also low.

For evaluation of muscular weakness the side difference is of importance. By using the ratio of the affected to the non-affected side, bias from age, sex, motivation, and day-to-day variations can be reduced. In this study we found a significant difference between the affected side and non-affected side. The difference was moderate (20–30%), and could have been difficult to evaluate without a dynamometer. It must be noted, however, that if a patient has a severe pain in one side, this can also influence the muscle strength recordings on the non-affected side and the ratio might not reflect the true difference between the sides. The ratio of the affected side to the non affected side might not change with time even if the muscular strength increased because of less pain. Because of this, we also analysed the absolute value of muscle strength of the affected side. It was found to improve in all groups over time. In between-groups comparison, there was a slight preference for surgery at control 2, but at control 3 there was no such difference between groups. This shows that the calculation using the ratios of affected to non-affected side and that using the absolute value of muscle strength both follow a similar pattern, which mutually strengthens their validity as measures of the effect of treatment on muscle strength.

The pain duration in our patients was long lasting and most patients had undergone different forms of treatment, such as physiotherapy, chiropractic, massage, acupuncture or zone therapy, or tried a soft collar, which is commonly used in clinical practice, before they were referred to the Department of Neurosurgery. Patients without earlier treatment with a collar or other forms of physiotherapy were equally distributed between the treatment groups. Some investigators have studied the effects of cervical collar in patients with cervical spondylotic myelopathy and found good results [50]. Some authors reject the use of a collar and consider early motion as important for good outcome of neck pain [35]. In a prospective study with patients with cervico-brachial pain there was, however, no difference between those treated by collar and those treated with physiotherapy and traction [13].

From the literature it is difficult to compare measurements of muscle weakness and sensory loss after surgical or conservative treatment. Most of the articles are retrospective, the follow-up times differed widely, as did the selection of patients. Patients with myelopathy and radiculopathy are sometimes mixed. The pre-surgery treatment is not always described, nor whether a patient was treated with a collar, bed rest or physiotherapy after surgery. The outcome is usually described only with respect to pain, and the neurological deficit is not always documented. If signs are described, the measurements are often not objective and seldom performed by an unbiased observer.

Motor loss in the arms without myelopathy has been reported by several authors [12, 20, 40], but this has not been objectively measured. Few studies have shown the occurrence of specific symptoms after surgery. Functionally good results are sometimes claimed based on combination scores of symptoms such as pain, numbness, sensibility loss and muscle weakness mixed together, as in the studies by White et al. [60] and Henderson et al. [29], with 91% and 98% good results respectively, or by Espersen et al. [21], with a 46% good functional result after surgery. In one long-term follow up of 122 patients, 63% had sensory loss and 45% had muscle weakness before surgery (manually tested). At follow-up 2–15 years after surgery, 96% had recovered motor function and 92% had regained sensation [11]. Motor deficit and brachialgia showed the best improvements after surgery in another study of 109 patients treated with surgery for cervical radiculopathy [7]. Of these, 77% had motor deficit symptoms before surgery. Sensory deficit before surgery was 81%, and 53% improved or were cured. Lunsford et al. [36] found in a postoperative questionnaire that about 75% of patients responded positively regarding sensory symptoms. They also found a significant difference in the improvement of motor function between soft disk and hard disk cases (80% vs 64% recovery).

In a retrospective study of 43 patients with radiculopathy due to foraminal stenosis or herniated nucleus pulposus, 23% had residual symptoms in their arms and 14% had subjective numbness in the fingers [12]. Recurrent symptoms requiring a second operation were found by Williams et al. in 25% of patients who had been completely asymptomatic immediately after surgery [61]. Eriksen and co-workers, in a study of 1,106 patients with cervical disk disease, found that disabling symptoms were still present in 45% of the patients after surgery, and that patients with a duration of paresis of over 6 months had poorer results [20]. In our study all patients had suffered more than 3 months pain, with a median of 21 months, although not always continuously. Pre-operative sick-leave was 11 months (median). It is possible that the overall improvement would have been better in all groups if pain history had been shorter.

Conclusions

Pain intensity, muscle weakness and sensory loss can be expected to improve within a few months after surgery, while with conservative treatment there is a slower improvement. Some of the surgery-treated patients improved immediately but had recurrent symptoms, probably related to the preceding degeneration of adjacent cervical levels. The 1-year outcome shows no significant differences between surgical and conservative therapy.

Acknowledgements This investigation was supported by grants from the Thelma Zoegas Fondation for Medical Research, the Malmöhus County Council Care Committee, and Medical Health Care Research in South Sweden (HSF).

References

1. Agre JC, Magness JL, Hull SZ, Wright KC, Baxter TL, et al (1987) Strength testing with a portable dynamometer: reliability for upper and lower extremities. Arch Phys Med Rehabil 68:454–458
2. Altman DG (1991) Practical statistics for medical research. Chapman and Hall, London, pp 440–476
3. Backman E, Johansson V, Hager B, Sjoblom P, Henriksson KG (1995) Isometric muscle strength and muscular endurance in normal persons aged between 17 and 70 years. Scand J Rehabil Med 27:109–117
4. Balogun JA, Onigbinde AT (1992) Hand and leg dominance: do they really effect limb muscle strength? Physiother Theory Pract 8:89–96
5. Barnes MP, Sanders M (1984) The effect of cervical mobility on the natural history of cervical spondylotic myelopathy. J Neurol Neurosurg Psychiatry 47:17–20
6. Benini A (1987) Clinical features of cervical root compression C5-C8 and their variations. Neuroorthopedics 4:74–88
7. Bertalanffy H, Egger H-R (1988) Clinical long-term results of anterior discectomy without fusion for treatment of cervical radiculopathy and myelopathy. Acta Neurochir 90:127–135
8. Blair SJ, McCormick E, Bear-Lehman J, Ewing Fess E, Rader E (1987) Evaluation of impairment of the upper extremity. Clin Orthop 221:42–58
9. Bohannon RW (1986) Test-retest reliability of hand-held dynamometry during a single session of strength assessment. Phys Ther 66:206–209
10. Bohannon RW, Andrews AW (1987) Interrater reliability of hand-held dynamometry. Phys Ther 67:931–933
11. Bohlman HH, Emery SE, Goodfellow DB, Jones PK (1993) Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. J Bone Joint Surg [Am] 9:1298–1307
12. Brigham CD, Tsahakis PJ (1995) Anterior cervical foraminotomy and fusion. Surgical technique and results. Spine 20:766–770
13. British Association of Physical Medicine (1966) Pain in the neck and arm: a multicentre trial of the effects of physiotherapy. BMJ 1:253–258
14. Clements DH, O'Leary PF (1990) Anterior cervical discectomy and fusion. Spine 15:1023–1025
15. Cloward RB (1958) The anterior approach for removal of ruptured cervical disks. J Neurosurg 15:602–617
16. DePalma AF, Subin DK (1965) Study of the cervical syndrome. Clin Orthop 38:135–141
17. Depassio J (1992) Treatment of cervicobrachial neuralgia in orthopaedic medicine. J Neuroradiol 19:197–203
18. Desrosiers J, Hébert R, Bravo G, Dutil E (1995) Comparison of the Jamar dynamometer and the Martin vigorimeter for grip strength measurements in a healthy elderly population. Scand Rehabil Med 27:137–143
19. Ellenberg MR, Hornet JC, Treanor WJ (1994) Cervical radiculopathy. Arch Phys Med Rehabil 75:342–352
20. Eriksen EF, Buhl M, Frode K, et al (1984) Treatment of cervical disc disease using Cloward's technique. The prognostic value of clinical preoperative data in 1106 patients. Acta Neurochir 70:181–197
21. Espersen JO, Buhl M, Eriksen EF, et al (1984) Treatment of cervical disc disease using Cloward's technique. General results, effects of different operative methods and complications in 1106 patients. Acta Neurochir 70:97–114
22. Fager CA (1993) Identification and management of radiculopathy. Neurosurg Clin N Am 4:1–12
23. Feinstein B, Langton JNK, Jameson RM, Schiller F (1954) Experiments on pain referred from deep somatic tissues. J Bone Joint Surg [Am] 36:981–997
24. Garfin SR, Rydevik B, Lind B, Massie J (1995) Spinal nerve root compression. Spine 16:1810–1820
25. Garvey TA, Eismont F (1991) Diagnosis and treatment of cervical radiculopathy and myelopathy. Orthop Rev 20:595–603
26. Gore DR, Sepic SB, Gardner GM, Murray MP (1987) Neck pain: a long-term follow-up of 205 patients. Spine 1:1–5
27. Hadley MN, Sonntag VKH (1993) Cervical disc herniations. The anterior approach to symptomatic interspace pathology. Neurosurg Clin North Am 1:45–52
28. Hamilton A, Balnave R, Adams R (1994) Grip strength testing reliability. J Hand Ther 7:163–170

29. Henderson CM, Hennessy RG, Shuey HM, Shackelford EG (1983) Posterior-lateral foraminotomy as an exclusive operative technique for cervical radiculopathy: a review of 846 consecutively operated cases. Neurosurgery 13:504–512
30. Herkowitz HN, Kurz LT, Overholt DP (1990) Surgical management of cervical soft disc herniation. A comparison between the anterior and posterior approach. Spine 10:1026–1030
31. Highland TR, Dreisinger TE, Vie LL, Russel GS (1992) Changes in isometric strength and range of motion of the isolated cervical spine after eight weeks of clinical rehabilitation. Spine 6 [Suppl]:77–82
32. Huskisson EC (1974) Measurement of pain. Lancet 7889:1127–1131
33. Huston GJ (1988) Collars and corsets. BMJ 296:276
34. Kendall HO, Kendall FP, Wadsworth GE (1971) Muscles, testing and function, 2nd edn. Williams and Wilkins, Baltimore London
35. Krusen EM (1968) Cervical pain syndromes. Arch Phys Med Rehabil 7: 376–382
36. Lunsford LD, Bissonette DJ, Jannetta PJ, Sheptak PE, Zorub DS (1980) Anterior surgery for cervical disc disease. 1. Treatment of lateral cervical disc herniation in 253 cases. Neurosurgery 53:1–11
37. MacDermid JC, Kramer JF, Woodbury MG, McFarlane RM, Roth JH (1994) Interrater reliability of pinch and grip strength measurements in patients with cumulative trauma disorders. J Hand Ther 7:10–14
38. Mannerfelt L (1966) Studies on the hand in ulnar nerve paralysis. A clinical-experimental investigation in normal and anomalous innervation. Acta Orthop Scand Suppl 87
39. Marzo J M, Simmons EH, Kallen F (1987) Intradural connections between adjacent cervical spinal roots. Spine 12:964–968
40. Matsunaga S, Sakou T, Imamura T, Morimoto N (1993) Dissociated motor loss in the upper extremities. Spine 4:1964–1967
41. Monro P (1984) What has surgery to offer in cervical spondylosis? In: Warlow C, Garfield JC (eds) Dilemmas in the management of neurological patients. Churchill Livingstone, Edinburgh, pp 168–187
42. Murray MP, Gore DR, Gardner GM, Mollinger LA (1985) Shoulder motion and muscle strength of normal men and women in two age groups. Clin Orthop 192:268–273
43. Naylor JR, Mulley GP (1991) Surgical collar: a survey of their prescription and use. Br J Rheumatol 30:282–284
44. Nurick S (1972) The natural history and the results of surgical treatment of the spinal cord disorders associated with cervical spondylosis. Brain 95: 101–108
45. Oberg T, Oberg U, Karsznia A (1994) Handgrip and finger pinch strength. Physiother Theory Pract 10:27–34
46. Persson LC, Moritz U (1994) Pain-drawing: a quantitative and qualitative model for pain assessment in cervicobrachial pain syndrome. Pain Clin 1: 13–22
47. Persson LC, Carlsson J, Carlsson C-A (1997) Long-lasting cervical radicular pain treated with surgery, physiotherapy or a cervical collar. A prospective randomised study. Spine 22(7)
48. Riddle DL, Finucane SD, Rothstein J M, Walker ML (1989) Intrasession and intersession reliability of hand-held dynamometer measurements taken on brain- damaged patients. Phys Ther 69:182–194
49. Robinson RA, Walker AE, Ferlic DC, Wieckling DK (1962) The results of anterior interbody fusion of the cervical spine. J Bone Joint Surg [Am] 8: 1569–1587
50. Rowland LP (1992) Surgical treatment of cervical spondylotic myelopathy: time for a controlled trial. Neurology 42:5–13
51. Rydevik B, Brown MD, Lundborg G (1984) Pathoanatomy and pathophysiology of nerve root compression. Spine 1:7–15
52. Rydevik BL, Pedowitz RA, Hargens AR, Swenson MR, Myers RR, et al (1991) Effects of acute, graded compression on spinal nerve root function and structure. An experimental study of pig cauda equina. Spine 16:487–493
53. Samii M, Völkening D, Sephernia A, Penkert G, Baumann H (1989) Surgical treatment of myeloradiculopathy in cervical spondylosis. A report on 438 operations. Neurosurg Rev 12:285–290
54. Simons FA. (1992) Cervical disc disease with radiculopathy. In: Rothman RH, Simione FA (eds) The spine, 3rd edn. Saunders, Philadelphia, pp 553–559
55. Spijkerman DCM, Snijders CJ, Stijnen T, Lankhorst GJ (1991) Standardization of grip strength measurements. Scand J Rehabil Med 23:203–206
56. Tan JC, Nordin M (1992) Role of the physical therapy in treatment of cervical disc disease. Orthop Clin North Am 23:435–449
57. Thorngren K-G, Werner C-O (1979) Normal grip strength. Acta Orthop Scand 50:255–259
58. Travell JG, Simons DG (1983) Myofascial pain and dysfunction. The trigger points manual. Williams and Wilkins, Baltimore, pp 5–44
59. Viikari-Juntura E, Porr SM, Laasonen EM (1989) Validity of clinical tests in the diagnosis of root compression in cervical disc disease. Spine 14:253–257
60. White AA, Southwick WO, Deponte RJ, Gainor JW, Hardy R (1973) Relief of pain by anterior cervical spine fusion for spondylosis. J Bone Joint Surg [Am] 55:525–534
61. Wlliams JL, Allen MB, Harkess JW (1968) Late results of cervical discectomy and interbody fusion: some factors influencing the results. J Bone Joint Surg 2:277–286