Pomeranian J Life Sci 2024;70(2):24-28 doi: 10.21164/pomjlifesci.992

Degenerative cervical spine disease: review of pathomechanism, diagnostics, and treatment

Bartosz Limanówka[A] ✉, Leszek Sagan[B]

Pomeranian Medical University in Szczecin, Department of Neurosurgery and Pediatric Neurosurgery, Unii Lubelskiej 1, 70-252 Szczecin, Poland

[A] ORCID: 0000-0002-7440-0088; [B] ORCID: 0000-0001-5366-1070

✉ blimanowka@gmail.com

ABSTRACT

Cervical spondylosis is the most common progressive disease of the cervical spine. As a disease that directly affects the function and morphology of the spinal cord and nerve roots, it is of particular interest to neurologists and neurosurgeons. However, due to its prevalence, physicians of all specialties encounter this disease. This article summarizes the current knowledge of the pathomechanism, diagnostics, and treatment of cervical spondylosis.

Keywords: cervical spondylosis; discopathy; degenerative spine disease; myelopathy; radiculopathy.

INTRODUCTION

Cervical spondylosis is the most common progressive disease of the cervical spine. As a disease that directly affects the function and morphology of the spinal cord and nerve roots, it is of particular interest to neurologists and neurosurgeons.

PATHOGENESIS

The primary pathological change is degeneration of individual anatomical components of the cervical spine. Spondylotic changes in the cervical spine are most commonly observed at the C5/C6 and C6/C7 levels [1, 2].

Secondary compression of the spinal cord or its vessels is responsible for the development of myelopathy. White and Panjabi divided the causative factors into static and dynamic. The static components of the pathological mechanism are a primary degenerative process that leads to a decrease in the sagittal dimension of the spinal canal. These include: degeneration of intervertebral discs, osteophytes of vertebral bodies and articular processes growing into the lumen of the spinal canal, hypertrophy of yellow ligaments and posterior longitudinal ligament, and congenital spinal stenosis. Dynamic components are forces acting on nerve structures during movement, which are greater than in a healthy person. Their occurrence is associated with the appearance of primary degenerative changes [3].

Narrowing of the sagittal dimension of the spinal canal typically begins with dehydration of the intervertebral disc. The increasing loss of water, proteins, and mucopolysaccharides with age leads to loss of elasticity, shrinkage, and fibrosis of the nucleus pulposus. As a result, the biomechanical load on the annulus fibrosus increases, which, together with the reduction in the height of the nucleus pulposus, leads to its encroachment into the lumen of the spinal canal [4, 5, 6]. The decrease in the height of the intervertebral disc is more pronounced in its anterior part. As a result, greater loads are transmitted through the anterior part of the disc, which can lead to progressive loss of lordotic alignment of the cervical spine [6]. The layers of the annulus fibrosus are thinner in the posterior portion, allowing the nucleus pulposus to migrate into the lumen of the spinal canal and form a herniation [4].

The strength of the endplates of adjacent vertebrae decreases in the central part and increases in the peripheral part with the progressive degeneration of the intervertebral disc, which leads to a change in the distribution of forces. The loads transmitted through the annulus fibrosus also increase [7], resulting in the separation of its fibers and deformation of the posterior longitudinal ligament from the edge of the vertebral body. Bone remodeling is observed in the area of the dorsal parts of the endplates, leading to the formation of osteophytes that narrow the width of the spinal canal [8]. The load on the intervertebral joints increases as a result of lowering the height of the intervertebral disc, resulting in the hypertrophy of the articular surfaces and the formation of osteophytes, which can narrow the foramina [4].

Secondary, dynamic components of the pathophysiology of cervical spondylosis are associated with narrowing of the spinal canal during motion [3, 9]. Flexion can compress the spinal cord through osteophytes located at the edges of the pedicles; this mechanism is more pronounced in patients with cervical kyphosis [4, 10, 11]. Extension may be associated with dorsal cord compression by hypertrophied yellow bands [4, 8, 10, 12]. Dynamic narrowing of the spinal canal is twice as common in extension as in flexion [13]. Smaller changes have also been shown to occur during lateral flexion and rotation [12]. Even the presence of primary lesions can lead to subluxations resulting in cord compression [3, 4].

Reduced mobility of the cervical spine in patients with advanced degenerative changes has been demonstrated [14].

CLINICAL SYMPTOMS

Most cases of degenerative spine disease are asymptomatic. Symptoms are most often associated with compression of the neural structures of the spinal canal. They typically include neck pain, radiculopathy, myelopathy, vertebrobasilar circulation disorders, and cervical headaches.

Neck pain typically occurs without the presence of a precipitating factor. The most common cause is discopathy and its sequelae, less commonly degenerative changes in the intervertebral joints [15]. Neck pain as an isolated symptom is associated with changes in structures innervated by the meningeal branch of the spinal nerve, i.e., nucleus pulposus, intervertebral joints, posterior longitudinal ligament, dura mater, and vertebral periosteum [16].

Radiculopathy is a symptom with acute, subacute, and chronic form. It is caused by direct compression of the nerve root. The most common cause of radiculopathy in patients under 55 years of age is herniated nucleus pulposus. Above this age, osteophytes forming stenosis of the spinal canal or intervertebral foramina remain the main mechanism [17]. Radiculopathy may be unilateral or bilateral, symmetrical or asymmetrical. Motor changes (muscle weakness, atrophy) occur in a higher percentage of patients with soft nucleus herniation. In patients with hard disc degeneration, the sensory component of radiculopathy dominates (paresthesia, hypoesthesia, hyperesthesia, hyperalgesia) and the occurrence of motor changes is associated with the chronicity of the disease [16].

Myelopathy may progress rapidly or remain stationary with relatively few symptoms. It most commonly affects patients over 50 years of age and is more common in men [4, 5, 17, 18]. It is caused by the static and dynamic factors described previously in the mechanism of direct compression of the spinal cord or its vessels [4, 3, 9]. The main symptom of cervical myelopathy is the insidious development of central and peripheral motor neuron deficits below and above the injury, respectively [16]. Damage to the central motor neuron is manifested by gait disturbances due to spastic paresis of the lower limbs, often with its characteristic hyperreflexia and pathological symptoms (e.g., Babiński sign, clonuses) [5, 9, 18]. Progressive myelopathy is accompanied by deep sensory abnormalities, indicating damage to the dorsal columns of the spinal cord [16, 19]. In severe cases, central motor neuron dysfunction may also occur in the upper limbs. Symptoms of peripheral motor neuron injury in the upper extremities are similar to those of radiculopathy [16]. Fasciculations in the distal parts of the upper limbs and sphincter dysfunction are observed relatively late [4, 18].

Vertebrobasilar circulation disorders develop due to dynamic flow disturbances in the vertebral artery passing through the foramina of the C6-C1 transverse processes. The main symptom is vertigo. Osteophytes formed in the degenerative process directly compress the vessel during head torsion [20, 21, 22, 23, 24].

Cervical headache is most commonly located in the occipital region, but its extension to the front of the head is known. Its etiology remains unclear. The original theory suggested direct compression of the C1, C2, and C3 roots that form the occipital nerves and subsequent irritation of the trigeminal nerves through connections between them [25, 26]. On the other hand, anterior cervical discectomy with fusion treatment for lower levels of the cervical spine has been shown to be effective for cervical headache [27, 28, 29]. Other hypotheses point to irritation of the dura and spinal cord as another cause of cervical headache [28, 30].

RADIOLOGICAL IMAGING

Classic radiological methods include X-rays and myelography. Nowadays, computed tomography (CT) and magnetic resonance imaging (MRI) are used.

Analysis of radiographs (Fig. 1) may reveal a reduction in the height of the intervertebral spaces, osteophytosis of the spinal canal and intervertebral foramina, disturbance of sagittal balance, subluxation, and compression due to hypertrophied articular surfaces. Functional radiographs can be helpful in identifying instability [4, 15, 31].

FIGURE 1. Lateral X-ray of the cervical spine with advanced spondylosis

Computed tomography (Fig. 2) remains useful for assessing intervertebral foramina, spinal canal width, and the size and shape of intervertebral joints. This imaging modality is not useful for assessing the neural structures of the spinal canal [4, 31].

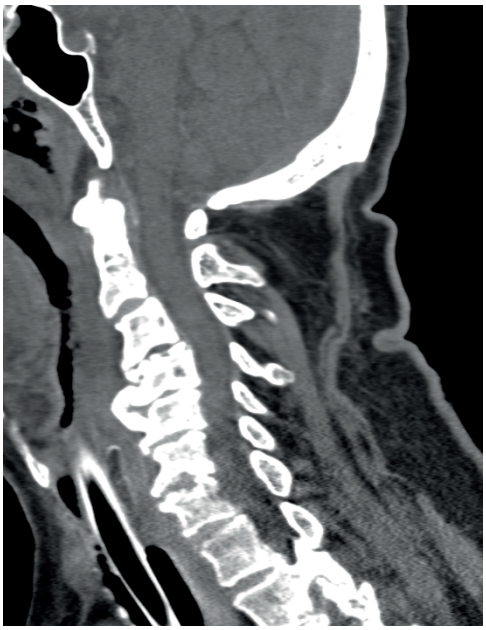

FIGURE 2. Sagittal computed tomography of the cervical spine in advanced spondylosis

Magnetic resonance imaging remains the main reference test (Fig. 3) which allows assessment of spinal cord morphology, intervertebral discs, ligaments, and spinal canal width [4, 15, 19, 31]. In patients with myelopathy, changes in the spinal cord signal on T2-weighted images are observed, corresponding to edema, inflammation, ischemia, myelomalacia, or gliosis [19]. Only in the case of detailed assessment of bone structure, CT is dominant [15].

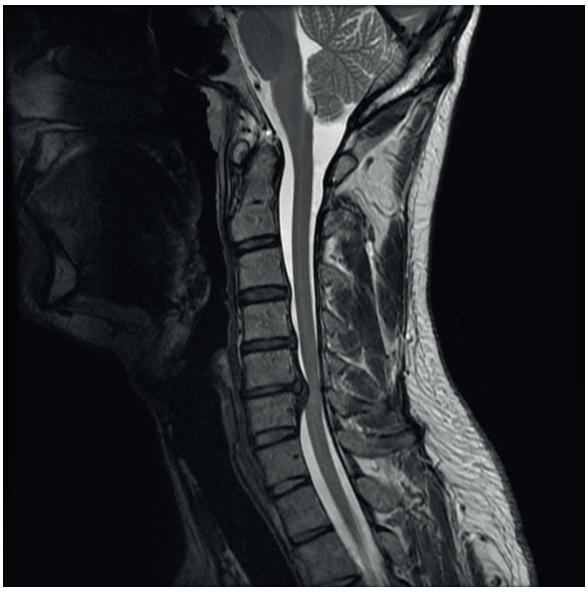

FIGURE 3. Sagittal T2-weighted magnetic resonance imaging image showing advanced C5/C6 discopathy

NATURAL HISTORY AND TREATMENT OPTIONS

The natural history of cervical degenerative radiculopathy is mild. Herniated nucleus pulposus often resolves spontaneously [32, 33, 34]. Degenerative cervical myelopathy may progress rapidly or remain stationary with relatively mild symptoms [4, 5, 17, 18].

Treatment options for neck pain and cervical radiculopathy include conservative management, physical therapy, and surgery. The only randomized clinical trial comparing the use of a cervical collar, physiotherapy, and surgery for the treatment of cervical radiculopathy showed the superiority of surgery for pain relief at 4 months. At 16 months, there were no differences between the 3 methods in pain, muscle strength, and sensory disturbances [35, 36]. In an older randomized trial, there were no differences in the reduction of radiculopathy symptoms between various conservative methods and placebo. Pain relief was demonstrated in 75% of patients during a 4-week observation period [37].

Conservative treatment typically begins with lifestyle modification, including avoidance of triggers. Pharmacotherapy usually involves the use of non-steroidal anti-inflammatory drugs [38, 39]. There is no proven association between the use of glucocorticoids and pain relief [40]. The benefits associated with the use of the cervical collar are at least controversial [35, 36, 41, 42]. Long-term use leads to atrophy of the paravertebral muscles [29, 41, 43].

Kinesitherapy has been shown to be effective in relieving local and radicular symptoms, but its effectiveness in radiculopathy is not fully established [35, 44, 45, 46]. Some reports suggest that manual therapy may be effective for short-term pain relief. However, in the absence of sufficient confirmation and the risk of serious complications, it is not recommended for use in patients with cervical spondylosis [47, 48, 49, 50].

Selective cervical root blocks have recently been recognized as a therapeutic and diagnostic tool, but their effectiveness is not fully proven [33, 51, 52].

Biological therapy in cervical degenerative spine diseases should not be applied through minimally invasive techniques due to anatomical conditions. Research focuses on the analysis of the effect of stem cells administered during anterior surgery on bone union and adjacent segment degeneration. The obtained results are inconsistent, and so far the positive effect of biological therapy in the treatment of cervical spondylosis has not been proven [53, 54, 55].

Among patients with radiculopathy, those with neurological deficits and prolonged or intolerable pain are eligible for surgical treatment [2, 8, 9, 38, 42, 43, 56]. Myelopathy is a mandatory indication. Surgery is also recommended for patients with cervical stenosis that threatens to damage the spinal cord [3, 5, 9, 19, 42, 56]. The effectiveness of the procedures has been confirmed in patients with vertebrobasilar circulation disorders and cervical headaches [22, 27, 28, 29].

Clinical practice guidelines approved by the Polish Society of Spinal Surgery include, among others, the following recommendations. Cervical spondylosis with radiculopathy with

concomitant signs of irritation or deficits may be treated surgically. Patients treated surgically should be symptomatic, with correlation between radiological imaging and clinical presentation. Considering the favorable natural history of the disease, the advantage of surgical treatment over conservative treatment is caused by faster recovery from pain. In cases of pain with radiculopathy, surgical treatment should be proposed after 6 weeks of ineffective conservative treatment. Patients in remission should not be treated surgically [57].

The main goal of surgical treatment of degenerative diseases is to decompress the neural structures of the spinal canal. Types of treatment can be divided into decompression, stabilization, and combination of both techniques. In practice, the division into anterior and posterior approaches is used. The type of degenerative pathology determines the choice of approach [58]. Anterior approaches are used for anterior cervical discectomy with fusion, artificial disc replacement, and corpectomy. They are most often used to treat radiculopathy and myelopathy caused by anterior compression of nerve structures. Posterior approach allows to perform laminectomy, laminoplasty, skip-split laminectomy, laminectomy with stabilization, and laminoforaminotomy. In addition, these methods are used to treat pathologies compressing dorsal nerve structures and myelopathy caused by multilevel and multidirectional degenerative changes [5, 9, 38, 42, 43, 56, 58, 59].

The most recent research, based on long-term follow-up of patients after anterior cervical discectomy with fusion, demonstrates greater than 90% efficacy in reducing neck and upper extremity pain and approx. 80% improvement in muscle strength and superficial sensation [56, 60, 61].

There are relatively few studies evaluating the cost-effectiveness of surgical treatment of degenerative spine disease compared with conservative management. Most of these are for lumbar spondylosis and show a neutral or positive economic effect of surgery [62, 63]. Studies evaluating cervical spine surgery indicate a high cost-effectiveness of treatment of cervical myelopathy compared with persistence of symptoms [64, 65]. In addition, anterior cervical discectomy with fusion is expected to be more cost-effective than artificial disc replacement [66].

REFERENCES

1. Boden SD, McCowin PR, Davis DO, Dina TS, Mark AS, Wiesel S. Abnormal magnetic-resonance scans of the cervical spine in asymptomatic subjects. A prospective investigation. J Bone Joint Surg Am 1990;72(8):1178-84.
2. Bohlman HH, Emery SE, Goodfellow DB, Jones PK. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. J Bone Joint Surg Am 1993;75(9):1298-307.
3. White AA, Panjabi MM. Biomechanical considerations in the surgical management of cervical spondylotic myelopathy. Spine 1988;13(7):856-60.
4. Ferguson RJ, Caplan LR. Cervical spondylitic myelopathy. Neurol Clin 1985;3(2):373-82.
5. Emery SE. Cervical spondylotic myelopathy: diagnosis and treatment. J Am Acad Orthop Surg 2001;9(6):376-88.
6. Benzel EC, Kayanja M, Fleischman A, Roy S. Spine biomechanics: fundamentals and future. Clin Neurosurg 2006;53:98-105.
7. Grant JP, Oxland TR, Dvorak MF, Fisher CG. The effects of bone density and disc degeneration on the structural property distributions in the lower lumbar vertebral endplates. J Orthop Res 2002;20(5):1115-20.
8. Saunders RL, Wilson DH. The surgery of cervical disk disease: new perspectives. Clin Orthop Relat Res 1980;(146):119-27.
9. Arnasson O, Carlsson CA, Pellettieri L. Surgical and conservative treatment of cervical spondylotic radiculopathy and myelopathy. Acta Neurochir 1987;84(1-2):48-53.
10. Hirabayashi K, Bohlman HH. Multilevel cervical spondylosis. Laminoplasty versus anterior decompression. Spine 1995;20(15):1732-4.
11. Uchida K, Nakajima H, Sato R, Yayama T, Mwaka ES, Kobayashi S, et al. Cervical spondylotic myelopathy associated with kyphosis or sagittal sigmoid alignment: outcome after anterior or posterior decompression. J Neurosurg Spine 2009;11(5):521-8.
12. Panjabi M, White AA 3rd. Biomechanics of nonacute cervical spinal cord trauma. Spine 1988;13(7):838-42.
13. Muhle C, Weinert D, Falliner A, Wiskirchen J, Metzner J, Baumer M, et al. Dynamic changes of the spinal canal in patients with cervical spondylosis at flexion and extension using magnetic resonance imaging. Invest Radiol 1998;33(8):444-9.
14. Hilibrand AS, Balasubramanian K, Eichenbaum M, Thinnes JH, Daffner S, Berta S, et al. The effect of anterior cervical fusion on neck motion. Spine 2006;31(15):1688-92.
15. Garfin SR. Cervical degenerative disorders: etiology, presentation, and imaging studies. Instr Course Lect 2000;49:335-8.
16. Connell MD, Wiesel SW. Natural history and pathogenesis of cervical disk disease. Orthop Clin North Am 1992;23(3):369-80.
17. Truumees E, Herkowitz HN. Cervical spondylotic myelopathy and radiculopathy. Instr Course Lect 2000;49:339-60.
18. Baron EM, Young WF. Cervical spondylotic myelopathy: a brief review of its pathophysiology, clinical course, and diagnosis. Neurosurgery 2007; 60(1 Supp 11):S35-41.
19. McCormick WE, Steinmetz MP, Benzel EC. Cervical spondylotic myelopathy: make the difficult diagnosis, then refer for surgery. Cleve Clin J Med 2003;70(10):899-904.
20. Fujita N, Ueda T, Yamanaka T, Inui H, Minami Y, Miyahara H, et al. Clinical application of ultrasonic blood rheography in vertebral artery for vertigo. Acta Otolaryngol Suppl 1995;519:178-83.
21. Kuether TA, Nesbit GM, Clark WM, Barnwell SL. Rotational vertebral artery occlusion: a mechanism of vertebrobasilar insufficiency. Neurosurgery 1997;41(2):427-32.
22. Ogino M, Kawamoto T, Asakuno K, Maeda Y, Kim P. Proper management of the rotational vertebral artery occlusion secondary to spondylosis. Clin Neurol Neurosurg 2001;103(4):250-3.
23. Cagnie B, Barbaix E, Vinck E, D'Herde K, Cambier D. Extrinsic risk factors for compromised blood flow in the vertebral artery: anatomical observations of the transverse foramina from C3 to C7. Surg Radiol Anat 2005;27(4):312-6.
24. Bulsara KR, Velez DA, Villavicencio A. Rotational vertebral artery insufficiency resulting from cervical spondylosis: case report and review of the literature. Surg Neurol 2006;65(6):625-7.
25. Vincent M. Validation of criteria for cervicogenic headache. Funct Neurol 1998;13(1):74-5.
26. Vincent MB. Cervicogenic headache: the neck is a generator: con. Headache 2010;50(4):706-9.
27. Schrot RJ, Mathew JS, Li Y, Beckett L, Bae HW, Kim KD. Headache relief after anterior cervical discectomy: post hoc analysis of a randomized investigational device exemption trial: clinical article. J Neurosurg Spine 2014;21(2):217-22.
28. Sun Y, Muheremu A, Yan K, Yu J, Zheng S, Tian W. Effect of different surgical methods on headache associated with cervical spondylotic myelopathy and/or radiculopathy. BMC Surg 2015;15(1):105.
29. Muheremu A, Sun Y, Yan K, Yu J, Zheng S, Tian W. Effect of Anterior Cervical Discectomy and Fusion on Patients with Atypical Symptoms Related to Cervical Spondylosis. J Neurol Surg A Cent Eur Neurosurg 2016;77(5):395-9.
30. Muheremu A, Sun Y. Atypical symptoms in patients with cervical spondylosis might be the result of stimulation on the dura mater and spinal cord. Med Hypotheses 2016;91:44-6.
31. Alker G. Neuroradiology of cervical spondylotic myelopathy. Spine 1988;13(7):850-3.

32. Spurling RG, Segerberg LH. Lateral intervertebral disk lesions in the lower cervical region. J Am Med Assoc 1953;151(5):354-9.
33. Bush K, Chaudhuri R, Hillier S, Penny J. The pathomorphologic changes that accompany the resolution of cervical radiculopathy. A prospective study with repeat magnetic resonance imaging. Spine 1997;22(2):183-6.
34. Vinas FC, Wilner H, Rengachary S. The spontaneous resorption of herniated cervical discs. J Clin Neurosci 2001;8(6):542-6.
35. Persson LC, Carlsson CA, Carlsson JY. Long-lasting cervical radicular pain managed with surgery, physiotherapy, or a cervical collar. A prospective, randomized study. Spine 1997;22(7):751-8.
36. Persson LC, Moritz U, Brandt L, Carlsson CA. Cervical radiculopathy: pain, muscle weakness and sensory loss in patients with cervical radiculopathy treated with surgery, physiotherapy or cervical collar. A prospective, controlled study. Eur Spine J 1997;6(4):256-66.
37. Pain in the neck and arm: a multicentre trial of the effects of physiotherapy, arranged by the British Association of Physical Medicine. Br Med J 1966;1(5482):253-8.
38. Woods BI, Hilibrand AS. Cervical radiculopathy: epidemiology, etiology, diagnosis, and treatment. J Spinal Disord Tech 2015;28(5):E251-9.
39. Wong JJ, Côté P, Ameis A, Varatharajan S, Varatharajan T, Shearer HM, et al. Are non-steroidal anti-inflammatory drugs effective for the management of neck pain and associated disorders, whiplash-associated disorders, or non-specific low back pain? A systematic review of systematic reviews by the Ontario Protocol for Traffic Injury Management (OPTIMa) Collaboration. Eur Spine J 2016;25(1):34-61.
40. Haimovic IC, Beresford HR. Dexamethasone is not superior to placebo for treating lumbosacral radicular pain. Neurology 1986;36(12):1593-4.
41. Levine MJ, Albert TJ, Smith MD. Cervical Radiculopathy: Diagnosis and Nonoperative Management. J Am Acad Orthop Surg 1996;4(6):305-16.
42. Mazanec D, Reddy A. Medical management of cervical spondylosis. Neurosurgery 2007;60(1 Supp1 1):S43-50.
43. Carette S, Fehlings MG. Clinical practice. Cervical radiculopathy. N Engl J Med 2005;353(4):392-9.
44. Kogstad OA, Karterud S, Gudmundsen J. Cervicobrachialgia. A controlled trial with conventional therapy and manipulation. Tidsskr Nor Laegeforen 1978;98(16):845-8.
45. Hoving JL, de Vet HC, Koes BW, Mameren H, Devillé WL, van der Windt DA, et al. Manual therapy, physical therapy, or continued care by the general practitioner for patients with neck pain: long-term results from a pragmatic randomized clinical trial. Clin J Pain 2006;22(4):370-7.
46. Kay TM, Gross A, Goldsmith CH, Rutherford S, Voth S, Hoving JL, et al. Exercises for mechanical neck disorders. Cochrane Database Syst Rev 2012(8):CD004250.
47. Di Fabio RP. Manipulation of the cervical spine: risks and benefits. Phys Ther 1999;79(1):50-65.
48. Tseng SH, Lin SM, Chen Y, Wang CH. Ruptured cervical disc after spinal manipulation therapy: report of two cases. Spine 2002;27(3):E80-2.
49. Schliesser JS, Kruse R, Fallon LF. Cervical radiculopathy treated with chiropractic flexion distraction manipulation: A retrospective study in a private practice setting. J Manipulative Physiol Ther 2003;26(9):E19.
50. Gross AR, Hoving JL, Haines TA, Goldsmith CH, Kay T, Aker P, et al. Manipulation and mobilisation for mechanical neck disorders. Cochrane Database Syst Rev 2004(1):CD004249.
51. Anderberg L, Annertz M, Rydholm U, Brandt L, Säveland H. Selective diagnostic nerve root block for the evaluation of radicular pain in the multilevel degenerated cervical spine. Eur Spine J 2006;15(6):794-801.
52. Bush K, Hillier S. Outcome of Cervical Radiculopathy Treated with Periradicular/Epidural Corticosteroid Injections. Pain Med 2015;16(12):2414-5.
53. Khashan M, Inoue S, Berven SH. Cell based therapies as compared to autologous bone grafts for spinal arthrodesis. Spine 2013;38(21):1885-91.
54. Schutgens EM, Tryfonidou MA, Smit TH, Öner FC, Krouwels A, Ito K, et al. Biomaterials for intervertebral disc regeneration: past performance and possible future strategies. Eur Cell Mater 2015;30:210-31.
55. McAnany SJ, Ahn J, Elboghdady IM, Marquez-Lara A, Ashraf N, Svovrlj B, et al. Mesenchymal stem cell allograft as a fusion adjunct in one- and two--level anterior cervical discectomy and fusion: a matched cohort analysis. Spine J 2016;16(2):163-7.
56. Galbraith JG, Butler JS, Dolan AM, O'Byrne JM. Operative outcomes for cervical myelopathy and radiculopathy. Adv Orthop 2012;2012:919153.
57. Latka S, Miekisiak G, Jarmuzek P, Lachowski M, Kaczmarczyk J. Treatment of degenerative cervical spondylosis with radiculopathy. Clinical practice guidelines endorsed by The Polish Society of Spinal Surgery. Neurol Neurochir Pol 2016;50(2):109-13.
58. Bartolomei J, Sonntag VK. Spine, Anterior approach including cervical corpectomy (degenerative). In: Winn HR, editor. Youmans neurological surgery edition. Vol. 4. Philadelphia: Saunders; 2004. p. 4431-46.
59. Mummaneni PV, Kaiser MG, Matz PG, Anderson PA, Groff MW, Heary RF, et al. Cervical surgical techniques for the treatment of cervical spondylotic myelopathy. J Neurosurg Spine 2009;11(2):130-41.
60. Yue WM, Brodner W, Highland TR. Long-term results after anterior cervical discectomy and fusion with allograft and plating: a 5- to 11-year radiologic and clinical follow-up study. Spine 2005;30(19):2138-44.
61. Shiban E, Gapon K, Wostrack M, Meyer B, Lehmberg J. Clinical and radiological outcome after anterior cervical discectomy and fusion with stand-alone empty polyetheretherketone (PEEK) cages. Acta Neurochir 2016;158(2):349-55.
62. Shvartzman L, Weingarten E, Sherry H, Levin S, Persaud A. Cost-effectiveness analysis of extended conservative therapy versus surgical intervention in the management of herniated lumbar intervertebral disc. Spine 1992;17(2):176-82.
63. Tosteson AN, Skinner JS, Tosteson TD, Lurie JD, Andersson GB, Berven S, et al. The cost effectiveness of surgical versus nonoperative treatment for lumbar disc herniation over two years: evidence from the Spine Patient Outcomes Research Trial (SPORT). Spine 2008;33(19):2108-15.
64. Witiw CD, Smieliauskas F, Fehlings MG. Health Economics and the Management of Degenerative Cervical Myelopathy. Neurosurg Clin N Am 2018;29(1):169-76.
65. Fehlings MG, Jha NK, Hewson SM, Massicotte EM, Kopjar B, Kalsi-Ryan S. Is surgery for cervical spondylotic myelopathy cost-effective? A cost-utility analysis based on data from the AOSpine North America prospective CSM study. J Neurosurg Spine 2012;17(1 Suppl):89-93.
66. Ament JD, Yang Z, Nunley P, Stone MB, Kim KD. Cost-effectiveness of cervical total disc replacement vs fusion for the treatment of 2-level symptomatic degenerative disc disease. JAMA Surg 2014;149(12):1231-9.