Eur Spine J (2007) 16:1387–1393
DOI 10.1007/s00586-006-0286-6

ORIGINAL ARTICLE

# Modified transcorporeal anterior cervical microforaminotomy for cervical radiculopathy: a technical note and early results

**Gun Choi · Sang-Ho Lee · Arun Bhanot · Yu Sik Chae · Byungjoo Jung · Seungcheol Lee**

Received: 14 February 2006 / Revised: 25 April 2006 / Accepted: 3 December 2006 / Published online: 3 January 2007


**Abstract** A prospective analysis of the first twenty patients operated for cervical radiculopathy by a new modification of transcorporeal anterior cervical foraminotomy technique. To evaluate early results of a functional disc surgery in which decompression for the cervical radiculopathy is done by drilling a hole in the upper vertebral body and most of the disc tissue is preserved. Earlier approaches to cervical disc surgery either advocated simple discectomy or discectomy with fusion, ultimately leading to loss of motion segment. Posterior foraminotomy does not address the more common anterior lesion. Twenty patients suffering from cervical radiculopathy not responding to conservative treatment were chosen for the new technique. Upper vertebral transcorporeal foraminotomy was performed with the modified technique in all the patients. All the patients experienced immediate/early relief of symptoms. No complications of vertebral artery injury, Horner's syndrome or recurrent laryngeal nerve palsy were noted. Modified transcorporeal anterior cervical microforaminotomy is an effective treatment for cervical radiculopathy. It avoids unnecessary violation of the disc space and much of the bony stabilizers of the cervical spine. Short-term results of this technique are quite encouraging. Longer-term analysis can help in outlining the true benefits of this technique.

G. Choi (✉) · S.-H. Lee · A. Bhanot · Y. S. Chae · B. Jung · S. Lee
Department of Neurosurgery,
Wooridul Spine Hospital, 47-4, Chungdam-Dong,
Gangnam-Gu, Seoul 135-100, Korea
e-mail: choigun@wooridul.co.kr

**Keywords** Cervical radiculopathy · Transcorporeal · Foraminotomy

## Introduction

Cervical radiculopathy is mainly a disease of the anterior relations of the cervical nerve root, with disc herniation and uncovertebral osteophytes accounting for the majority of cases [15, 25]. Until now, posterior laminoforaminotomy and anterior discectomy with or without fusion have been the standard surgical treatments for this disease group. However, all these techniques have been associated with the limitations of indirect decompression, technical difficulties due to excessive bleeding and fusion related adjacent segment disease etc. [8, 12, 13, 15].

Since 1968, various authors have tried to use anterior microforaminotomy for decompression of these lesions but many were still removing either a part or the whole of the intervertebral disc tissue to achieve their goal [10, 16, 27, 30]. Jho, in 1996, was the first to attempt a disc sparing surgery via a transuncal approach that was later modified by Saringer and subsequently by Jho himself in 2002 [14, 15, 23]. The latest technique by Jho [15] utilizes a drill hole made into the inferolateral part of the upper vertebral body along with medial 1–2 mm of transverse foramen.

The authors wish to describe a modification of Jho's technique of upper vertebral trancorporeal anterior microforaminotomy to treat cervical radiculopathy, which is safer and easier. The new technique avoids breaching the medial wall of the transverse foramen, attempting to preserve the lower end plate and is located more medially than Jho's technique. We report

a prospective analysis of the clinical results of the first twenty patients treated by this technique. To the best of our knowledge, this is the first prospective report on a purely upper vertebral transcorporeal foraminotomy technique for cervical radiculopathy.

## Material and methods

### Patient population

Between May 2004 and December 2005, forty-one consecutive patients were operated for cervical radiculopathy with the new modified technique at the authors' institute. Out of these, the first twenty patients with a minimum follow-up of 1-year and above constitute the subject of this study. The patients were considered for surgery on the basis of: (1) Unilateral cervical radiculopathy not responding to conservative treatment of more than 6 weeks (or earlier if the patients continued to have severe radicular symptoms not controlled with opioids), (2) Imaging studies corresponding to the clinical features, and (3) Absence of cervical spondylotic myelopathy symptoms.

Fifteen were men and five women with an average age of 48.7 years (range 37–74 years, and the average duration of symptoms was 19.8 months (range 0.5–96 months). All except two patients were given a trial of at least 6 weeks of conservative treatment before being considered for surgery. The two patients who were operated on at 2 weeks after the onset of symptoms had a severe radiculopathy (VAS 8 and 9) not responding to medical and physical treatment. Table 1 shows the distribution of clinical symptoms along with the type of lesion and their level.

All the patients were investigated with X-rays (standard cervical spine series-AP, Lateral, Oblique, Flexion and Extension views), MRI and CT scans to outline the nature and exact site of the incriminating lesion (Table 1). CT scans were also utilized for preoperative measurement of the depth and direction of the drill hole trajectory. Patients suffering from multilevel disease, bilateral involvement and spinal canal stenosis were not considered in this study. The new surgical procedure was performed after obtaining due permission from the local institutional review board as well as informed consent from the patients.

Follow-up evaluation consisted of regular follow up at 6 weeks, 3 months, 6 months, and 1 year and at 6-month interval subsequently. At each follow up visit, VAS scores for radicular pain and neck pain were assessed. Any requirement for oral analgesics/opioids was inquired about. Neck Disability Index (NDI) was measured and compared with preoperative values. Prolo's [21] economic and functional scale was employed to judge the overall outcome of the surgical intervention at the last follow-up visit. An independent third party observer assessed NDI and Prolo scores.

Disc height and disc height index measurements were done as per method of Lu et al. modified by An et al. in which the disc height was calculated by an average of measurements obtained from the anterior, middle and posterior portions of the Intervertebral Disc (IVD) and this value was divided by the average of sum of adjacent vertebral body heights to calculate the Disc Height Index (DHI) [1, 17]. This helped in avoiding the errors of magnification and positioning while taking X-rays. All these measurements were done on a Picture Archiving and Communication System (PACS workstation, Mediface, Seoul, Korea). An independent observer calculated all the values twice, and the average of the two readings was taken as the final value.

The results were analyzed statistically by paired Student's $t$ test and the confidence level was kept at $P < 0.05$.

### Surgical technique

The intended skin incision level is identified with the help of a marker X-ray film taken in the operating room. The surgical approach is made from the affected side similar to the conventional anterior cervical discectomy except that the 3–4 cm transverse skin incision is made at one level higher than the affected disc level (i.e., for a C5-6 disc herniation, the skin incision would be like that for C4-5). Access to the cervical spine is

**Table 1** Clinical features, type of lesion and affected level

| Demographics | Number of patients (%) |
|---|---|
| Preoperative clinical features | |
| Neck pain | 16 (80%) |
| Interscapular pain | 4 (20%) |
| Shoulder pain | 2 (10%) |
| Radicular pain | 20 (100%) |
| Sensory loss | 5 (25%) |
| Motor weakness | 16 (80%) |
| Tendon reflex abnormalities | 7 (35%) |
| Type of lesion | |
| Soft disc herniation | 7 (35%) |
| Spondylotic stenosis with osteophyte | 3 (15%) |
| Soft disc with osteophyte | 10 (50%) |
| Level of pathology | |
| C6-7 | 14 (70%) |
| C5-6 | 4 (20%) |
| C4-5 | 1 (5%) |
| C7-T1 | 1 (5%) |

gained by sharp and blunt dissection through various layers of deep cervical fascia. Once the prevertebral fascia is opened, the midline on the anterior surface of upper vertebral body of affected segment is marked in relation to the two longus colli muscles (LCM). A marker X-ray film is taken to confirm the exposed level. The LCM attachment from its medial margin is erased subperiosteally with bipolar cautery, and self-retaining Caspar retractors (Aesculap, Tuttlingen, Germany) are applied under the LCM. In this technique, the affected disc level is exposed but there is no need to expose the lower vertebra of the affected segment. The position of the drill hole is 4–6 mm above the lower border of the exposed vertebra (approximately mid-body level), at the level of medial border of LCM. This is a relatively medial position than the earlier techniques. The trajectory of the tunnel is decided depending upon the location of the target identified on preoperative assessment of the offending pathology from imaging studies. Sometimes, anterior osteophytes may create confusion regarding the starting point of drill hole. Under such circumstances, the intraoperative marker film with a needle in the disc space can help chose the cephalo-caudal location and direction of the drill hole, in addition to the medial border of longus colli muscle serving as the starting point for the drill hole. If required, intraoperative C-arm can also be used for verification of the hole position and trajectory. A $6 \times 7$ mm drill hole is made from a medial to lateral direction so as to open into the foramen. Care is taken to avoid damage to the medial wall of the transverse foramen as well as to preserve the integrity of the underlying end plate especially in the anterior two-thirds of the disc (Figs. 1, 2a). Due to the obliquity of the cervical disc, this trajectory leads directly to the pathological site in the foramen (Figs. 3, 4). Initially a 4 mm matchstick type diamond burr is used with a high-speed drill (Black Max, Anspach, Palm Beach Gardens, FL, USA) to start the drill hole from the desired point. Subsequently we may need to change to a 3 mm burr tip for better visualization and fine drilling. In addition, the length of the drilling burr may also need to be changed to a longer one, as sometimes during the course of the drilling, the routine length burr tip does not allow easy drilling of the posterior vertebral region especially when the antero-posterior diameter of the vertebra is more than 20 mm. While using a longer burr, wobbling may be encountered when we use the distal tip of the burr for drilling. Extra care needs to be taken at this point to avoid any untoward injury. Once the posterior limit of the drill hole is reached, we can use the side-cutting edge of the longer burr tip to expand the hole. The posterior

**Fig. 1** Postoperative axial CT scan showing preservation of medial wall of foramina transversaria and opening into the intervertebral foramen

longitudinal ligament still acts as a protective barrier between the instruments and the neural structures. The spongy bone of the cervical vertebra acts as a visual guide for the progress of the drilling process. Using bone wax can help stop bleeding during the drilling of the spongy bone. When the thin, ivory white cortical shell of the posterior vertebral wall is encountered, the drilling is stopped, and gentle, careful lifting of the cortical shell is done with thin bone punches and curette. At this point, if some epidural bleeding is encountered, it can be managed by putting Avitene (MedChem Products, MA, USA) for some time, but use of bipolar coagulation is to be discouraged. After opening the posterior wall of the foraminotomy hole, we can visualize the herniated disc fragment (Fig. 5a) and the hypertrophied uncovertebral region, which can

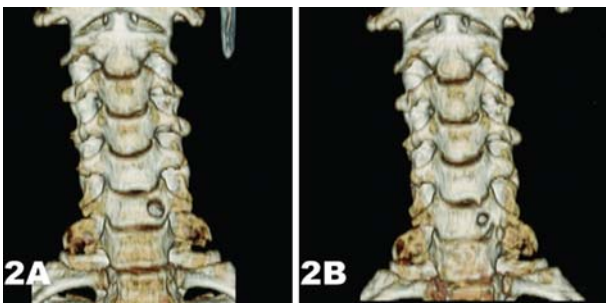


**Fig. 2** **a** (*left*) Immediate postoperative 3D reconstructed CT scan showing the position of the drill hole. **b** (*right*) Six-month follow-up 3D reconstructed CT scan of the same patient showing new bone formation at the drilled hole

**Fig. 3** Preoperative sagittal MRI image showing a paramedian and foraminal herniated disc at C6-7 level (*arrow*)

be gently removed with a combination of microcurettes, micro punch and blunt hook. This step may necessitate removal of a small part of the posterolateral disc tissue in some cases, to remove the uncinate osteophyte arising from the lower vertebral body. Finally, the adequacy of the foraminal decompression is checked by blunt hook palpation of the superior and inferior pedicles along the course of the nerve root and refilling of the nerve root sleeve with CSF (Fig. 5b) and CSF pulsation in the nerve root.

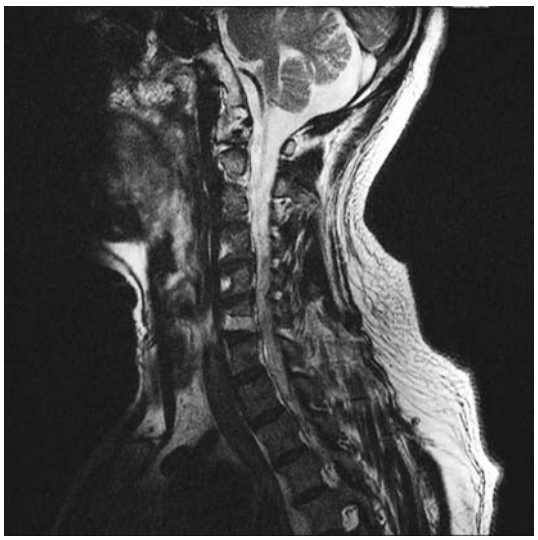

**Fig. 4** Postoperative MRI of the same patient showing adequate decompression and the direction of the drill hole

Postoperative protocol

The patients were discharged on first postoperative day with instructions to wear a soft collar for 2 weeks. Return to work was allowed as per rate of symptom improvement and patient comfort.

## Results

All patients experienced immediate/early relief of their radicular symptoms after the surgery. Two patients experienced a tingling sensation in the ipsilateral limb that subsided within 2 months. Neurological symptoms recovered in all the patients and the time to recovery was 2 weeks to 3 months. Average follow up period was 16.7 months (range: 12–21 months). Average preoperative and postoperative VAS scores for radicular pain were 7.8 ± 0.9 and 0.6 ± 0.8, respectively, showing an improvement of 92% ($P = 0$). Average preoperative and postoperative VAS scores for neck pain were 3.2 ± 1.9 and 1.1 ± 1.1, respectively, showing an improvement of 65% ($P = 0$). Average preoperative and postoperative Neck Disability Index (NDI) measurements were 55.6 ± 16.2 and 4 ± 3.7, respectively, showing an overall improvement of 92.8% ($P = 0$). All patients had a final Prolo score between 8 and 10 showing good outcome. None of the patients had a poor outcome. There was no case of Horner's syndrome or recurrent laryngeal nerve palsy.

Average preoperative and postoperative disc height measurements were 6.1 ± 0.7 and 5.7 ± 0.7 mm, respectively. Though the difference was statistically significant ($P = 0.005$), yet the percentage change in disc height was only 6% from the baseline value. Average preoperative and postoperative disc height index values were 0.38 ± 0.04 and 0.36 ± 0.04, respectively and the difference was statistically significant ($P = 0.03$). However, the loss in disc height seemed to stabilize after the first 3 months as measured on serial X-rays at longer follow-up periods. No case of postoperative instability was seen as measured on dynamic cervical spine X-rays.

## Discussion

Development and propagation of the anterior cervical approach, first by Smith and Robinson, and later by Cloward, ushered in an era of anterior cervical discectomy with or without fusion for the patients of cervical spondylotic radiculopathy [4, 26]. The treatment was well conceived in principle, with the idea of

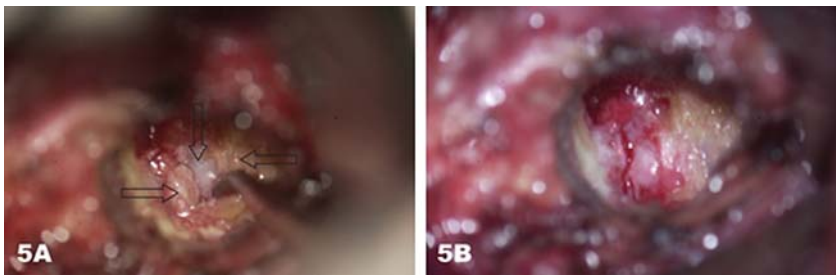


**Fig. 5** **a** (*left*) Intraoperative photograph showing the drilled hole and various anatomical structures that are visualized: ruptured disc fragment (*right arrow*), nerve root (*down arrow*), posterior longitudinal ligament (*left arrow*). **b** (*right*) Showing decompressed and expanded nerve root after removal of the ruptured disc fragment

direct anterior decompression of the offending structures, but it had the inherent disadvantages of loss of disc height (for discectomy without fusion cases) and fusion of a mobile motion segment [11, 19, 30]. One of the main complications associated with the loss of a motion segment is the adjacent segment disease, the incidence for which has been quoted from 25 to 81% in various long-term studies [5, 6, 13]. The cause of this adjacent segment disease, though not yet clear, has been postulated as the increased mechanical stress exertion leading to increased intradiscal pressure at the adjacent level, resulting in osmotic gradients and metabolic deficiencies [20, 28, 29]. In addition, the anterior fusion technique has also been fraught with a significant incidence of pseudoarthrosis and bone graft related problems [3, 18, 24]. On the other hand, indirect decompression via posterior foraminotomy has also been advocated for cervical radiculopathy, even when the pathology commonly lies anterior to the nerve root and is not directly touched by the surgical procedure [15, 22, 31]. This approach is more suited for cervical radiculopathy arising out of lateral disc herniation, focal lateral thickening of the ligamentum flavum, facet thickening and arthropathy [8, 15]. The laminoforaminotomy is also associated with the technical limitations of limited surgical view, difficulty in resecting osteophytes, limited visualization of the distal foramen and increased epidural bleeding [7]. In addition, higher incidence of postoperative muscle spasm, neck pain and long recovery time have been reported with this technique, probably due to the muscle dissection needed to obtain adequate surgical exposure [8]. Though many long-term studies have reported good outcome with laminoforaminotomy, still, this is not the ideal treatment for most of the patients of cervical radiculopathy who usually suffer from a combined pathology of soft disc herniation and spondylotic osteophytes lying anterior to the nerve root. On the other hand, bone fusion with elimination of a motion segment is not a physiological treatment [15].

Therefore, an anterior approach that would not affect the motion segment while at the same time providing an opportunity to decompress anterior pathological lesion becomes the natural choice in the evolution of treatment for cervical radiculopathy. This brings into focus what is known as the ''functional spine surgery''—a term coined by Jho [15]. Snyder and Bernhardt were the first to attempt a disc sparing non-fusion technique for anterior foraminal decompression, but their technique still required removal of the lateral one-third of the disc [27]. George et al. [9] revisited the original technique of Verbiest for oblique transcorporeal approach for anteriorly located lesions in the cervical spinal canal, but it needs to expose the vertebral artery with its inherent risks and is more suitable for lesions extending over a wide area.

Jho in 1996 [14] first described the transuncal anterior foraminotomy with the emphasis on preserving as much of the disc space as possible. But this technique still required exposing the vertebral artery along its medial surface. Saringer, in 2000, proposed a modification to Jho's transuncal technique by preserving a thin piece of cortical bone of the lateral wall of the uncinate process, thus avoiding exposure of the vertebral artery [23]. However, their technique required transverse cutting of the LCM for about 10–14 mm, leaving a scope for injury to the cervical sympathetic chain and Horner's syndrome. As both the above techniques used a lower vertebral transcorporeal approach, it placed the foraminotomy hole relatively caudal to the pathological lesion due to the obliquity of the cervical disc, thus requiring more bone and soft tissue excision to achieve adequate decompression. In 2002, Jho [15] reported an upper vertebral transcorporeal foraminotomy technique in his paper on results of various anterior microforaminotomy techniques, overcoming some of the disadvantages of the lower vertebral transcorporeal approach. The hole in this technique was drilled at the most lateral, inferior 4–5 mm portion of the upper level vertebral body and

the medial 1 or 2 mm portion of the transverse foramen was also drilled. The cartilage end plate was exposed and entered in its posterior third. The posterolateral portion of the lateral uncinate process, which often represented the pathology, was excised. By using this technique, Jho claimed that the surgical target could be more precisely approached and the disc height could also be preserved.

We agree with Jho's idea of approaching the sagitally oblique cervical disc through an upper transcorporeal approach. However, with our technique, the vertebral artery does not need to be exposed and endangered. As the cervical sympathetic chain lies relatively medially at lower cervical spine as compared to upper cervical spine (though still on the lateral border of LCM), placing the hole more medially helps in avoiding the risk of Horner's syndrome as well as any unnecessary retraction of the LCM, thus making this technique easier and simpler. There might arise a doubt about the feasibility of removal of osteophytes from the inferior lateral corner of the segment being treated through the drill hole. This problem is overcome by accurate preoperative planning regarding the direction and placement of drill hole. In addition, in certain cases, we may need to remove a part of the posterior and lateral disc to access that region. Despite this, the amount of disc tissue removed is very small and is not likely to have any impact on the stability of the segment. We would also like to submit here that this technique would be more suitable for lower cervical levels. For the upper cervical levels above C4–5, it is our presumption (though we do not have an experience so far) that a lower vertebral transcorporeal approach may prove better because of the disc inclination as well as difficulty with accessing the upper vertebral body due to interference by the mandible.

In our study, there was a minor but statistically significant loss of disc height and disc height index. Although this has not been reported previously, we think the previous published studies neither applied strict measuring criteria as used by us nor mentioned what method was used to assess the disc height. Another point worth mentioning here is that the loss in disc height was seen most significantly in the first 3 months after the surgery. In the subsequent X-rays taken at longer follow-up periods, the disc height loss stabilized and did not progress further. We postulate that this loss in disc height in the early postoperative period results from a relative lack of nutrition to the disc from the adjacent end plate that is partly handled during the surgery. Once the drilled hole is refilled with reparative new bone formation, this relative deficiency is eliminated and the disc height loss is halted.

There was no case of postoperative instability at the latest follow-up visit as measured by dynamic flexion and extension views. Though this observation was made from a short-term follow up, the stability is expected to remain the same in the long run as the loss in disc height stabilizes after 3 months and the previous literature also supports the evidence that minor loss in disc height and minor alterations in cervical sagittal curvature after anterior cervical discectomy without fusion do not affect the long-term outcomes in such patients [2]. A potential problem with this technique could be the risk of vertebral body collapse during the early postoperative period, as the drill hole creates a stress riser. However, we found this risk to be theoretical than actual as the drill hole occupied only 12% (1/8th) of the vertebral area and no such complication was seen in our study group. In addition, the drill hole was filled with new bone as seen at subsequent CT scan images (Fig. 2b).

Though the outcome observations in this series are based on a small number of patients, the excellent short-term results are encouraging. Lack of complications like Horner's syndrome and recurrent laryngeal nerve palsy and avoiding the danger to the vertebral artery prove the benefits of the current technique. Strict selection criteria and direct access to the offending lesions are some of the factors contributing to good outcome in a large number of patients.

## Conclusion

Modified transcorporeal anterior cervical microforaminotomy is a simple, effective, and minimally invasive technique for the treatment of cervical radiculopathy as it preserves most of the disc tissue. By placing the drill hole more medially, complications like Horner's syndrome and risk to vertebral artery associated with earlier reports can be avoided. The initial results with this technique have been encouraging, but a long-term assessment is needed to judge the true potential and benefits of this technique.

**Acknowledgments** We are thankful to Sung Hui Myung, Song-Woo Shin, and Chi Gon Oh for their help in preparing the manuscript.

## References

1. An HS, Takegami K, Kamada H et al (2004) Intradiscal administration of osteogenic protein-1 increases intervertebral disc height and proteoglycan content in the nucleus pulposus in normal adolescent rabbits. Spine 30:25–32

2. Benini A, Krayenbuhl H, Bruderl R (1982) Anterior cervical discectomy without fusion. Microsurgical technique. Acta Neurochir (Wien) 61(1–3):105–110
3. Clements DH, O'Leary PF (1990) Anterior cervical discectomy and fusion. Spine 15:1023–1025
4. Cloward RB (1958) The anterior approach for removal of ruptured cervical discs. J Neurosurg 15:602
5. DePalma AF, Rothman RH, Lewinnek GE et al (1972) Anterior interbody fusion for severe disc degeneration. Surg Gynecol Obstet 134:755–758
6. Dmitriev AE, Cunningham BW, Hu N et al (2005) Adjacent level intradiscal pressure and segmental kinematics following a cervical total disc arthroplasty: An in vitro human cadaveric model. Spine 30:1165–1172
7. Ebersold MJ, Raynor RB, Bovis GK et al (1999) Cervical laminotomy, laminectomy, laminoplasty and foraminotomy. In: Benzel EC (ed) Spine surgery:techniques, complication avoidance and management. Churchill Livingstone, London, pp 251–253
8. Fessler RG, Khoo LR (2002) Minimally invasive cervical microendoscopic foraminotomy: an initial clinical experience. Neurosurgery 51(Suppl 2):37–45
9. George B, Zerah M, Lot G et al (1993) Oblique transcorporeal approach to anteriorly located lesions in the cervical spinal canal. Acta Neurochir 121:187–190
10. Hakuba A (1976) Trans-unco-discal approach. A combined anterior and lateral approach to cervical discs. J Neurosurg 45:284–291
11. Hankinson HL, Wilson CB (1973) Use of the operating microscope in anterior cervical discectomy without fusion. J Neurosurg 43:452–456
12. Hilibrand AS, Carlson GD, Palumbo MA et al (1999) Radiculopathy and Myelopathy at segments adjacent to the site of a previous anterior cervical Arthrodesis. JBJS 81:519–528
13. Hilibrand AS, Yoo JU, Carlson GD et al (1997) The success of anterior cervical Arthrodesis adjacent to previous fusion. Spine 22:1574–1579
14. Jho HD (1996) Microsurgical anterior cervical foraminotomy. A new approach to cervical disc herniation. J Neurosurg 84:155–160
15. Jho HD, Kim WK, Kim MH (2002) Anterior microforaminotomy for treatment of cervical radiculopathy: part i—disc preserving ''functional cervical disc surgery''. Neurosurgery 51(Suppl-2):46–53
16. Lesoin F, Biondi A, Jomin M (1987) Foraminal cervical herniatied disc treated by anterior discoforaminotomy. Neurosurg 21:334–338
17. Lu DS, Shono Y, Oda I et al (1997) Effects of chondroitinase ABC and chymopapain on spinal motion segment biomechanics. An in vivo biomechanical, radiologic, and histologic canine study. Spine 22:1828–1834; discussion 34–35
18. Lundsford LD, Bissonette JD, Jannetta PJ et al (1973) Anterior surgery for cervical disc disease. Part 1: treatment of lateral cervical disc herniation in 253 cases. J Neurosurg 53:679–683
19. Martins AN (1976) Anterior cervical discectomy with and without interbody bone graft. J Neurosurg 44:290–295
20. Pospiech J, Stolke D, Wilke HJ et al (1999) Intradiscal pressure recordings in the cervical spine. Neurosurgery 44:379–385
21. Prolo DJ, Oklund SA, Butcher M (1986) Towards uniformity in evaluating results of lumbar spine operations: A paradigm applied to posterior lumbar interbody fusions. Spine 11(6):601–606
22. Raynor RB, Pugh J, Shapiro I (1985) Cervical facetectomy and the effect on spine strength. J Neurosurg 63:278–282
23. Sampath P, Bendebba M, Davis J et al (1999) Outcome in patients with cervical radiculopathy: prospective, multicenter study with independent clinical review. Spine 24:591–597
24. Saringer W, Nobauer I, Reddy M et al (2002) Microsurgical anterior cervical foraminotomy (Uncoforaminotomy) for unilateral radiculopathy: clinical results of a new technique. Acta Neurochir 144:685–694
25. Savoluinen S, Usenius JP, Hernesniemi J (1994) Iliac crest versus artificial bone grafts in 250 cervical fusions. Acta Neurochir 129:54–57
26. Schimandle JH, Boden SD (2003) Degenerative disorders of the cervical spine: cervical radiculopathy. In: Emery SE, Boden SD (eds) Surgery of the cervical spine, saunders. Elsevier Science, Philadelphia 94
27. Smith EW, Robinson RA (1958) The treatment of certain cervical spine disorders by anterior removal of the intervertebral disc and interbody fusion. JBJS [A] 40:607
28. Snyder GM, Bernhardt AM (1989) Anterior cervical fractional interspace decompression for treatment of cervical radiculopathy. A review of the first 66 cases. Clin Orthop 246:92–99
29. Urban JP, Holm S, Maroudas A et al (1977) Nutrition of the intervertebral disk. An in vivo study of solute transport. Clin Orthop Relat Res 101–114
30. Urban JP, Holm S, Maroudas A et al (1982) Nutrition of the intervertebral disc: effect of fluid flow on solute transport. Clin Orthop Relat Res 296–302
31. Verbiest H (1968) A lateral approach to cervical spine: technique and indications. J Neurosurg 28:191–203