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Cervical Laminoplasty - Principles, Surgical Methods, Results, and Issues

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Abstract

Cervical laminoplasty (CL) is one of the surgical methods via posterior approach for treating patients with cervical myelopathy. The main purpose of CL is to decompress the cervical spinal cord by widening the narrowed spinal canal, combined with preserving the posterior anatomical structures to the degree possible. At present, these surgical methods are broadly divided into two types from the viewpoints of the site of osteotomy: Double-door type (DDL) and Open-door type (ODL). Various materials are used to maintain the enlarged spinal canal such as autogeneous bone (spinous process, iliac bone), hydroxyapatite spacer, titanium plate and screw, thread, and so on. Although the surgical methods and techniques of CL and the methods of assessment are various, recovery rates have been reported to be about 60~70%. The main influential factors on the surgical results are the age of the patients, the duration of the diseases, accompanying injuries to the cervical spine, and the neurological findings just before surgery. CL can be safely performed and stable surgical results maintained for a long period; more than 10 years. However, patients with large prominence-type of ossification of the posterior longitudinal ligament (OPLL) and severe kyphotic alignment of the cervical spine are relatively contraindicated because of possibility of inadequate posterior shift of the spinal cord. This possibility can be predicted using K-line to some extent before surgery. Even now, there remain some issues to be resolved: the deterioration of neurological findings, especially in patients with continuous or mixed type OPLL, the postoperative kyphotic-directional alignment change of the cervical spine which may relate to its relative invasiveness to the posterior muscles, C5 palsy, and axial pain.

Keywords: Cervical spine; Laminoplasty; Posterior decompression; Principles; Issues

Introduction

Cervical laminoplasty (CL) is one of the surgical options for patients with cervical myelopathy, which is performed via posterior approach. The main purpose of CL is to decompress the cervical spinal cord by widening the narrowed spinal canal, combined with preserving the posterior anatomical structures as much as possible.

Various methods of CL have been developed in Japan since 1973, and these have gradually become common around the world. At present, these surgical methods are broadly divided into two types from the viewpoints of the site of osteotomy: Double-door type (DDL) and Open-door type (ODL). CL can be safely performed and stable surgical results maintained for a long period; more than 10 years. However, even now, there remain some issues to be resolved. In this paper, the principles, surgical methods, results, and issues of CL are discussed.

Mechanism of cervical myelopathy

In general, cervical myelopathy is related to narrowed spinal canal which may be congenital and/or acquired. Within the narrowed spinal canal, the spinal cord may be compressed due to both static and dynamic stress mechanisms. In chronic anterior and posterior compression, forces impact the spinal cord over a long period of time. As a result, the spinal cord gradually becomes degenerated and atrophied, causing neurological symptoms.

These mechanisms have been revealed by biomechanical experimental study using the cervical spinal cords of bovines and rabbits [1,2]. Ichihara et al. [1] revealed the difference of the mechanical properties between the white and gray matters in the bovine cervical spinal cord, that is, the gray matter is more rigid, although more fragile, than the white matter, and estimated the progressing mechanism of cervical myelopathy and the specific areas to be finally affected, that is, the gray matter and the posterolateral portion of the white matter.

Clinically, the histological changes within the spinal cord in patients with ossification of the posterior longitudinal ligament (OPLL) are revealed to be more significant in the gray matter than in the white matter [3]. In the gray matter, flattened anterior horn cells, loss and degeneration of the nerve cells, growth of the glial cells, and fibrous gliosis are revealed. In the white matter, demyelination can be mainly seen at the lateral and posterior funiculus. Although distinct obstruction of the small arteries within the spinal cord is not seen, fibrous degeneration of the adventitia in the small veins with narrowing of the lumen is revealed. These histological findings may indicate that cervical myelopathy due to OPLL is caused by not only mechanical stress but also secondary circulatory disturbance.

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Kameyama et al. [4] investigated the relationship between the findings of magnetic resonance imaging (MRI) and pathology of the spinal cord in cervical myelopathy. In the boomerang-shaped spinal cord on MRI, major pathological changes were restricted to the gray matter, and the white matter was relatively well preserved. Secondary wallerian degeneration was restricted to the fibers of fasciculus cuneatus derived from the affected segments. In the triangular-shaped spinal cord, pathological changes were more severe, and both the white and gray matters were involved. There were severe pathological changes over more than one segment, and the degeneration of both the descending and ascending tracts at the posterior column were observed.

Treatment of cervical myelopathy

In general, myelopathy may be caused by static and/or dynamic compression mechanisms. The main purpose of treatment of cervical myelopathy is firstly to decrease the mechanical stress. At the cervical spine where extension movement tends to be the main mechanism to cause dynamic compression, the conservative treatment of reducing its movement by using a collar is effective. For patients in whom conservative treatment is not so effective, the surgical intervention to decrease the stress due mainly to static mechanism must be introduced as the next step.

As for the surgical treatment for this situation, there are two methods from the viewpoint of approach; anterior decompression and posterior decompression. When preoperatively thinking about which approach must be selected, not only the pathologies of anterior space occupying lesions (SOL) and the alignment of the cervical spine, but also the degree of the anteroposterior diameter of the spinal canal and the number of intervertebral discs involved must be assessed.

In cases of OPLL, the spinal cord is compressed anteriorly, therefore, direct decompression via anterior approach is certainly reasonable. Usually, OPLL extends to multiple levels and narrows the spinal canal, especially in cases with continuous or mixed type. As a result, in the anterior approach, multi-level decompression and fixation must be performed. However, the direct multi-level decompression via anterior approach is technically demanding because of the deep and narrow surgical field, the limited working space, and the possibility of high volume bleeding during direct procedure on the OPLL, even if the OPLL is not completely resected but floated anteriorly. On the contrary, in the posterior approach, multi-level decompression can be easily performed because of the shallow and wide surgical field. Besides, the volume of bleeding during surgery is less than that in the anterior approach. Even after indirect decompression via posterior approach such as CL, the spinal cord can be shifted posteriorly and separated from the OPLL. Usually in most patients, the alignment of the cervical spine is lordotic, therefore, the spinal cord can be separated from the OPLL more effectively. Of course, in cases with large size of OPLL and/or severe kyphotic alignment of the cervical spine, the effect of posterior shift may be limited. Therefore, anterior decompression must be selected or sometimes added after posterior decompression, or posterior decompression combined with instrumented spine fusion must be selected [5,6].

In cases of disc herniation with a wide spinal canal, single-level decompression and fixation is usually performed. However, in cases combined with narrowed spinal canal, it may induce *de novo* myelopathy at the adjacent level sooner or later because of appearance of adjacent instability. Therefore, wide posterior decompression such as CL, or anterior decompression and fixation as the first step to be followed by CL as the second step may be reasonable.

Principles and history of CL

Previously, in Japan, laminectomy had been commonly performed as posterior decompression surgery. However, progressive spinal deformity (kyphotic or sigmoid type curvature), especially in relatively younger patients, constriction of the dura mater caused by extradural scar formation, postoperative spread of OPLL, spinal instability, and decreased spinal movement have been pointed out to result in some cases [7-9]. These problems had been thought to be caused by inevitable postoperative lack of tension by the removal of the posterior anatomical structures. Although all of these problems do not always deteriorate neurological conditions, some patients with progressive deformity had required early spinal fusion [8].

CL has been developed as one of the methods to fundamentally resolve these problems. With CL, the inherent antinomy, decompressing the spinal cord and preserving the posterior anatomical structures, can be simultaneously obtained.

In 1973, the idea of cervical laminoplasty was first proposed by Oyama and co-workers [10] under the name of "Expansive lamina-Z-plasty". Thereafter, various methods of cervical laminoplasty have been developed in Japan, and these have gradually become common around the world.

At present, the surgical methods of CL are broadly divided into two types from the viewpoints of the site of osteotomy [11,12]. Double-door type (DDL) [13-18] and Open-door type (ODL) [19-22]. Various materials are used to maintain the enlarged spinal canal such as autogeneous bone (spinous process [14,20], iliac bone [13]), hydroxyapatite spacer [11,12,15,17,21-25], titanium plate and screw [26,27], thread [19], and so on.

Why was CL developed in Japan? Probably, two reasons may be thought for this: narrower spinal canal in Japanese population and higher interest in OPLL by Japanese researchers. In Japanese people, the average antero-posterior (AP) diameter of the cervical canal at C5 level is 16 mm in males, and 15 mm in females [28,29]. These are narrower than those of people of western countries [30]. In Japan, the AP diameters of less than 14 mm in males and 13 mm in females are diagnosed as narrow canal stenosis, which has tendency of causing cervical myelopathy.

Additionally, there are many reports concerning a high prevalence rate of cervical OPLL in Japan: 1.9% [31] and 3.7% [32] on lateral X-ray films, and 6.3%[33] on positron emission tomography and computed tomography (PETCT). Matsunaga et al. [34] retrospectively reviewed that the prevalence of OPLL in the general Japanese population older than 30 years is 1.9% to 4.3%. This prevalence rate of cervical OPLL is higher among the Japanese than Caucasians [32]. However, whether OPLL is statistically more common in Japanese people or not and whether this difference in the prevalence is based on the racial difference or not is unclear because previous papers concerning OPLL have mainly been written by

Japanese researchers since 1960 when Tsukimoto [35] reported one case of OPLL. OPLL and OYL (ossification of the yellow ligament) are in fact called "Japanese disease". It is possible that the difference in the prevalence between Japan and western countries is largely based on the difference in the recognition of OPLL by researchers. In any case, there are many patients with cervical myelopathy in Japan.

Surgical techniques of CL

Surgical methods of Double-door laminoplasty (DDL): At present, there are many surgical methods of DDL from the viewpoints of method of osteotomy [13,17,36,37] and type of spacer used. In this paper, our recent surgical method [25] based on the original Kurokawa's method [13,38] is presented focusing on the procedure of the posterior muscle handling and the method of osteotomy.

In most patients, this surgery is performed at the levels between C3 (the third cervical) and C6. After longitudinal skin incision, the semispinalis cervicis muscles are detached from the C2 spinous process. After exposing the caudal side of C2 to the cranial side of C7, the caudal border of the C2 lamina is resected in a dome shape. From this procedure on, the spinous processes and laminae are split centrally in order from the C3 to C6. At first, a pyramidal-shaped osteotomy is made at the cranial base of the C3 spinous process to obtain a good visual field. Next, the remaining part of the spinous process is split centrally from its surface using an air-drill, and the split portion is connected to the pyramidal-shaped dome.

After central splitting is completed at each vertebra, a longitudinal groove of 3 mm in width is made bilaterally at the lamina-facet junction by resecting the outer cortex and a portion of cancellous bone. Finally, the cranial side of the C7 lamina is resected in a dome shape. After completing osteotomy, the constricting fibrous band above the dura mater and the hypertrophied yellow ligament are resected in order from the C6 to C3. At each level, the shape of the widened space is trapezoidal, both on the axial and frontal sections, because the cranial side of the widened space is more widely opened than the caudal side. A hole of 2 mm in diameter to accommodate a thread for fixing the spacer is made at about 8 mm or more superficial from the inner plate of the lamina. The spacer whose shape is the same as that of the widened space is firmly stabilized by slightly rotation to the appropriate position. Each spacer is fixed using one or two non-absorbable threads.

Before wound closure, the semispinalis cervicis muscles which are once detached from the C2 spinous process are sutured to the ipsilateral obliqeous capitus inferior muscles to restore their strength to the extent possible. The collar is discarded at the end of 1 month after surgery.

Surgical method of Open-door laminoplasty (ODL): Here, the surgical method of osteotomy and fixation of spacers are presented. In ODL, after making longitudinal grooves along the lamina-facet junction bilaterally, the inner cortex is severed at the open side. Next, the spinous processes are pushed toward the hinge side and the hypertrophied yellow ligament is resected. After complete decompression of the spinal cord, a spacer is inserted between the inner side of the facet joint and the base of the tilted lamina at each vertebra. Alternatively, a non-absorbable thread is used to tract the tilted lamina toward the hinge side to open the space.

Neurological recovery or deterioration after CL

As long as the decompression surgery is undertaken un-traumatically, the surgical results are thought to depend on the viability of the spinal cord of the patients at the time of surgery. In other words, the role of decompression surgery is thought to bring out the viability of the spinal cord *in situ* and provide a new circumstance in which the spinal cord can recover additional viability thereafter. It has been reported that the influential factors on the surgical results are the age of the patients, the duration of the diseases, accompanying injuries to the cervical spine, and the neurological findings just before surgery. All of these are the inner factors of the patients. From these results, it is naturally estimated that the milder the neurological findings before surgery, the better the surgical results can be expected. Therefore, it is important that the surgical intervention be made before the neurological conditions deteriorate. In contrast, prophylactic surgery should not be considered for patients with only slight neurological findings because their spinal cords may have adequate viability to recover by conservative treatment. In general, progression of muscle weakness and obvious severity of spasticity causing disability of handling of eating utensils and/or walking are main factors to indicate surgical intervention. Although the surgical methods and techniques of CL and the methods of assessment may differ, recovery rates have been reported to be about 60~70% in the literature [39-49]. This probably means that the surgeries had been indicated and performed for patients with such degree of viability of the spinal cord.

During a long time after surgery, the neurological findings may gradually deteriorate in some patients. The reasons for this deterioration are thought to be a worsening of the function of the spinal cord with aging, *de novo* formation and/or progression of thickness of the OPLL, degenerative changes at the thoracic and/or lumbar vertebral levels, progression of kyphotic alignment of the cervical spine, adjacent intervertebral disc changes, and so on [39-49]. Concerning the rate of progression of OPLL, there are some reports: 66%[40], 70% [41], and 73% [42] for more than 10 years follow-up. Younger age at the time of operation and continuous or mixed type of OPLL are highly predictive of progression of OPLL [41,42]. Seichi et al. reported that the occupancy rate of OPLL was higher in patients with neurological deterioration [50], and the main cause of neurological deterioration in patients with OPLL was a minor injury of the spinal cord at the remnant site of OPLL [39]. Of course, the deterioration in activity of daily living after surgery does not always relate to the deterioration in neurological findings, and it is sometimes due to other factors such as decreasing of muscle power itself and deterioration in the joint function of extremities with aging. Accordingly, the precise evaluation of surgery for cervical myelopathy after a long follow-up is sometimes difficult to perform with confidence.

C5 palsy after CL

Summary of C5 palsy: C5 palsy is defined as *de novo* or aggravating muscle weakness mainly at the C5 lesion with slight or no sensory disturbance after cervical surgery.

According to Sakaura et al. [51] who reviewed 343 cases, the features of C5 palsy are as follows: 1) One-half of the patients were accompanied by sensory disturbance or intolerable pain at the C5 lesion. 2) Ninety-two percent of patients had hemilateral palsy. 3) Almost all palsy occurred within a week after surgery. 4) In rare patients, palsy occurred at the C6, C7, or C8 lesion alone or combined.

Causes of C5 palsy: Even now, the precise cause of C5 palsy has not yet been revealed, probably because multiple factors relate to the occurrence. Among them, of course, there are obvious causes such as injury to the spinal cord or nerve root by an air-drill during surgery, compression of the nerve roots by a transplanted strut bone, and so on. At present, the uncertain causes are divided from the viewpoint of the time of onset and the kinds of nerve tissue involved.

During surgery, the spinal cord and/or the nerve root may be damaged by direct compression of a retractor and/or high friction heat of the tip of an air-drill [52]. After surgery, the spinal cord and/or the nerve root may be distracted and/or compressed by adjacent anatomical structures such as the facet joint and the vertebral body under a new circumstance in which the cervical spine alignment is more or less changed, especially when the patients start rehabilitation after bed rest. The fact that almost all palsy occur within a week after surgery is in favor of this idea.

Concerning the kinds of nerve tissue involved, there are two theories: the segmental spinal cord disorder theory and the nerve root injury theory. In the theory of segmental spinal cord disorder, it is thought that nerve tissues, especially the anterior horn cells, may be damaged due to ischemia before CL and/or recirculation after CL. At that time of acute recirculation, the nerve cells may be chemically damaged by reactive oxygen [53,54]. In this theory, why only C5 motor function is affected cannot be explained. In contrast, in the theory of nerve root injury, anterior rootlet or nerve root may be mechanically compressed and/or distracted [12,55-62]. From the theory of nerve root injury, the features of C5 palsy mentioned above can be well explained.

Anatomical investigation to reveal the cause of C5 palsy: Based on anatomical analysis using cadavers, we have concluded that this palsy is most likely caused by C5 nerve root compression and stretch near the exit of the foramen [12].

The essences of our analysis are as follows: 1) Among the cervical nerve roots composed of the brachial plexus, the distance between the division from the dura mater and the exit of the foramen is shortest at the C5 nerve root. This means that the capacity for moving freely is estimated to be smallest at the C5 nerve root, 2) The anterior rootlets run adjacent to the narrowest part of the foramen, that is, the tip of the superior facet joint. This means that the anterior rootlets of the cervical nerve tend to be stretched and compressed mechanically in the foramen. 3) The medial branch of the posterior ramus runs in the shortest distance in contact with the lateral side of the facet joint column. According to Zhang et al. [63], the length of the posterior ramus proper is shortest in C4 and C5 nerves. If the multifidus muscles are severely retracted laterally by hooks during posterior surgery, not only the medial branch of the posterior ramus but also the anterior and posterior rami and the anterior rootlet are simultaneously stretched and compressed against adjacent bone structures. In patients with hypertrophied facet joint due to degenerative changes, the influence of this stretching and compression are estimated to become larger, especially at C4 and C5 levels where the incidence of anterior prominence of the facet joint is highest [64]. This influence of stretching and compression is thought to become higher after decompression because of the posterior shift of the spinal cord within the spinal canal.

Various countermeasures to prevent C5 palsy: Even though it is unclear which theory is probable, real countermeasures to prevent C5 palsy must be clinically proposed. From the side of theory of nerve root injury, various countermeasures have been proposed.

We have recommended that too severe lateral stretch of the multifidus muscles for a long time must be avoided. During CL, intermittent relaxation of tension of the hooks to the muscles may be one method of solution [12].

In CL combined with dekyphosis surgery, foraminotomy is added in advance because C5 nerve may be compressed at the narrowed foramen by extension mechanism during dekyphosis procedure [56]. There are some reports [55,57-62] that the tethering-cord effect is a greater risk factor for C5 palsy, in which the nerve is thought to be stretched due to the posterior shift of the spinal cord after decompression. To prevent this mechanical effect, prophylactic foraminotomy [57,59,61] has been performed. Zhang et al. [60] reported the procedure where the open-door angle is maintained between 15 and 30 degrees in order not to shift the spinal cord excessive-posteriorly.

Local complaints after CL

Postoperative kyphotic-directional alignment change of the cervical spine: In posterior decompression surgery, how to control the postoperative kyphotic-directional alignment change is one of the important challenges. The postoperative kyphotic-directional alignment change is revealed not so relate so much to the deterioration of neurological findings in cervical spondylotic myelopathy but to deteriorate neurological findings in some cases of OPLL [40,50].

One method of solution is to recover the tension of posterior cervical muscles and the nuchal ligament as much as possible by preserving the spinous process as long as possible as an anterior support and re-suturing the semispinalis cervicis muscles which had been earlier detached from the C2 spinous process before closure [38]. We reported the alignment change in this method [25], that is, among 37 patients, 33 had lordotic alignment with an average of 14.0 degrees preoperatively, and this changed toward less lordotic or kyphotic postoperatively by about 10 degrees in 67 % of patients, and in 3 of 4 patients with preoperative kyphosis, the progression of kyphosis was also by about 10 degrees.

In ODL, the procedures of preservation of the funicular section of the nuchal ligament attached to the C6 and/or C7 spinous processes in addition to all muscles attached to the C2 and C7 spinous processes and the subaxial deep extensor muscles on the hinged side have been performed [21,65].

Shiraishi [15] developed a new surgical technique that preserved the attachments of semispinalis cervicis and multifidus muscles on the cervical spinous processes and limited the damage to the attachments of interspinous and rotator muscles. Comparing his method (skip laminectomy: SL) with ODL, the average postoperative range of neck motion was maintained at 98% of the preoperative measurement in SL and 61% in ODL, and the average atrophy rate of the deep extensor muscles was 13% in SL and 59.9% in ODL [46].

Kim et al. [17] developed a new surgical method in which the spinous process is split centrally with preserving the attachment of the posterior muscles to it, and after detaching the base of the spinous process from the lamina, central splitting of the lamina is performed. In this method, deep extensor muscles did not become atrophic, postoperative loss of lordosis was less than 1 degree, and the range of motion (ROM) of C2-C7 angle 1 year after surgery was 67.7% of preoperative value.

Axial pain after CL: The axial pain in a narrow sense is defined as pain and feeling of stiffness around the neck and shoulders after cervical surgery. It is clearly discriminated from pain caused by nerve tissues such as the spinal cord and nerve roots. According to Duetzmann et al. [66] who systematically reviewed 103 studies concerning cervical laminoplasty from 2003 to 2013, the percentage of patients who complained of postoperative axial pain was 30% at a mean follow-up of 51 months. Axial pain has significant negative correlations with health-related quality of life (HRQOL) [67].

Axial pain usually occurs when a patient starts to sit up on bed, and often to deteriorate on sitting and standing, and conversely improve on lying down [68]. In the beginning, the cause was thought to be related to resection of posterior deep muscles of cervical spine at the time of approach. However, later, it was thought to be likely related to release of deep muscles from C7 spinous process. After resection of the rhomboid minor muscle and the trapezius muscle from the tip of the C7 spinous process, the scapula rotates adductly on sitting and standing. This rotation of the scapula may induce pain and feeling of stiffness around the neck and shoulders. To prevent axial pain, the operation level of CL has been limited to from C3 to C6 and the C7 lamina has been cut in a dome-shape when involved. However, even after this countermeasure, some patients continue to have complaints. There are also controversies concerning the effectiveness of preservation of the attachment of the nuchal ligament to the C6 spinous process to reduce postoperative axial pain [69,70]. Recently, it has been thought that the cause of axial pain is possibly not single but multiple [71-73].

Wang et al. [73] reviewed 1297 cases in 26 studies concerning axial pain and concluded that potential sources of axial pain include the cervical disc, musculature, facet joints, spinal cord and nerve roots; and to prevent postoperative axial pain, early postoperative ROM exercise, shorter or no application of external immobilization, less surgical exposure, avoiding detachment of semispinalis cervicis muscle from C2 spinous process and reconstructing the extensor musculature as anatomically as possible are important.

Relative-contraindication of CL

In CL, the spinal cord are decompressed by shifting posteriorly. However, in cases with large OPLL, the effect of decompression may be incomplete. Fujiyoshi et al. [74] proposed the K-line to predict the postoperative posterior shift of the spinal cord. The K-line is defined as a line that connects the midpoints of the spinal canal at the C2 and C7 vertebral levels on lateral X-ray films in neutral position. K-line (-) is defined as the situation where the tip of the OPLL exceeds the K-line. They concluded that a sufficient posterior shift of the spinal cord and neurological improvement will not be obtained in the K-line (-) group. Thereafter, modified K-line using MRI [75,76] and different assessment methods of K-line in flexion [77] or extension position [78] have been reported. From the results of preoperative investigation using K-line, the surgical methods have been changed from CL to anterior decompression and fusion (ADF) [5] or posterior decompression and instrumented fusion (PDF) [6]. The K-line is one of practical markers for deciding the surgical approach and methods in patients with cervical OPLL.

Conclusion

CL can be safely performed and stable surgical results are maintained for a long period; more than 10 years. However, patients with large prominence-type of OPLL and severe kyphotic alignment of the cervical spine are relatively contraindicated because of possibility of inadequate posterior shift of the spinal cord. This possibility can be predicted to some extent using K-line before surgery. Even now, there remain some issues to be resolved: the deterioration of neurological findings, especially in patients with continuous or mixed type OPLL, the postoperative kyphotic-directional alignment change of the cervical spine which may relate to its relative invasiveness to the posterior muscles, C5 palsy, and axial pain.

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