Review Article

Factors predicting loss of cervical lordosis following cervical laminoplasty: A critical review

ABSTRACT

Background: Laminoplasty is a method of posterior cervical decompression which indirectly decompresses the spinal column. Unfortunately, many patients undergoing laminoplasty develops postoperative loss of cervical lordosis (LCL) or kyphotic alignment of cervical spine even though they have sufficient preoperative lordosis which results in poor surgical outcome.

Objective: We would like to highlight the relationship between various radiological parameters of cervical alignment and postoperative LCL in patients undergoing laminoplasty.

Methods: We performed extensive literature search using PubMed, Google Scholar, and Web of Science for relevant articles that report factors affecting cervical alignment following laminoplasty.

Results: On reviewing the literature, patients with high T1 slope have more lordotic alignment of cervical spine preoperatively. They also have more chances of LCL following laminoplasty. C2–C7 sagittal vertical axis (SVA) has no role in predicting LCL following laminoplasty though patients with low T1 slope (20) and high C2–C7 SVA (>22 mm) had correction of kyphotic deformity following laminoplasty. C2–C7 lordosis, Neck Tilt, cervical range of motion, and thoracic kyphosis has no predictive value for LCL. Lower value of T1 slope (T1S-CL) and CL/T1S has more incidence of developing LCL following laminoplasty. The role of C2–C3 disc angle has not yet been evaluated in patients undergoing laminoplasty. Dynamic extension reserve determines the contraction reserve of SPMLC and lower dynamic extension reserve is associated with higher chances of LCL following laminoplasty.

Conclusions: Cervical lordotic alignment is important in maintaining cervical sagittal balance which ultimately is responsible for global spinal sagittal balance and horizontal gaze. Among various radiological parameters, T1 Slope has been reported to be the most important factor affecting cervical alignment following laminoplasty.

Keywords: C2–C7 Cobb's angle, C2–C3 disc angle, C2–C7 lordosis, C2–C7 sagittal vertical axis, cervical laminoplasty, dynamic extension reserve, loss of cervical lordosis, T1 slope

INTRODUCTION

The lordotic curvature of the cervical spine provides the sagittal balance of the cervical spine which is of immense importance in maintaining the global spinal balance.[1] If there is sagittal imbalance in any part of spine, then other parts of spine try to compensate for maintaining the sagittal balance. As for example, hyperkyphosis of the cervical spine will result in increased lumbar lordosis whereas hyperlordosis would lead to increased lumbar kyphosis as a compensatory mechanism.[2] Disorders of other parts of spine are usually compensated by cervical spine as it is the most mobile segment of the spine.[3]

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Cervical lordosis (CL) is necessary to maintain the forward gaze and any injury to this lordotic alignment of cervical spine results in pain and functional disability.[4] Cervical spondylotic myelopathy (CSM) is the most common degenerative disease of the cervical spine, which often requires surgical correction with laminoplasty or laminectomy. For mild and nonprogressive CSM; conservative, nonoperative, medical management suffice whereas surgical management is reserved for moderate to severe cases.[5,6] Although in terms of long term clinical and radiological outcome laminectomy has superior results,[7,8] laminoplasty is still favored for CSM as it preserves the cervical range of motion (ROM) without causing instability[8,9] and the incidence of postoperative kyphosis is lower in laminoplasty.[10-12]

Laminoplasty is a method of posterior cervical decompression which indirectly decompresses the spinal column.[13] For successful laminoplasty, maintenance of CL is mandatory both in the preoperative and the postoperative period. Unfortunately, many patients undergoing laminoplasty develops postoperative loss of cervical lordosis (LCL) or kyphotic alignment of cervical spine even though they have sufficient preoperative lordosis which results in poor surgical outcome or a need for redo-surgery among them. Hence, it becomes imperative to select proper patients for laminoplasty. Other than the preoperative CL, T1 slope is one such measurement which can be evaluated prior to selecting cases for cervical laminoplasty.[14]

Several studies have shown that despite initial lordotic cervical sagittal alignment, the degree of CL decreases in the postoperative period as T1 slope increases.[15-17] The absence of CL preoperatively minimizes the decompressive effect of laminoplasty and hence it T1 slope is an important factor in patients undergoing laminoplasty preoperatively.[14]

In this article, we would like to highlight the relationship between various radiological parameters of cervical alignment and postoperative LCL in patients undergoing laminoplasty.

METHODS

Measures of cervical alignment

Various studies have described various indices to predict LCL in patients undergoing laminoplasty.[18-21] The indices which may play an important role in predicting LCL are described in Table 1 and Figure 1.

RESULTS

Correlation of various indices in predicting LCL postlaminoplasty:

Table 1: Description of indices affecting cervical alignment

Indices	Description
C2-C7 SVA	Distance between the posterosuperior corner of C7 vertebral body and the vertical line from the center of the C2 vertebralbody
T1 slope	Angle between the superior endplate of T1 vertebral body and the horizontal line parallel to floor
CL	Angle measured between the inferior endplates of C2 and C7 vertebral body
Cervical ROM	Sum of the C2-C7 Cobb angle during flexion and extension lateral radiographs
NT	Angle formed by a line drawn at the superior end of the sternum and a line connecting the center of the T1 superior end plate and the superior end of sternum
TK	Cobbs angle between the superior endplate of T3 and the inferior endplate of T12 on whole standing lateral radiograph
CVLL	Highest vertebral level of laminoplasty
C2-C3 disc angle	Angle created by the line drawn parallel to the C2-3 disc space and the line parallel to the floor
DER	Difference between the extension C2-C7 Cobbs angle and neutral C2-C7 Cobbs angle

SVA - Sagittal vertical axis, NT - Neck tilt, TK - Thoracic kyphosis, CVLL - Cephalad vertebral level undergoing laminoplasty, DER - Dynamic extension reserve, CL - C2–C7 lordosis, ROM - Range of motion

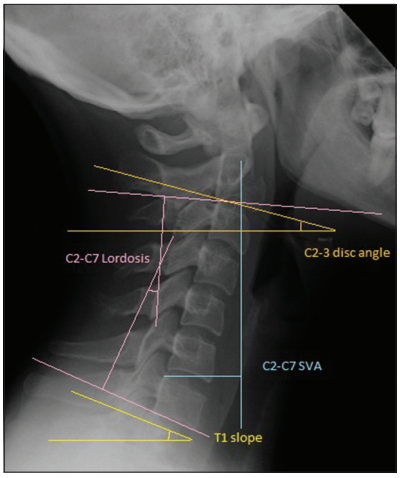

Figure 1: The lateral X-ray of cervical spine showing various radiological measurements

T1 slope

T1 slope is one of the most important indices which can predict loss CL following laminoplasty. Many studies were conducted to evaluate the role of T1 slope in predicting the LCL following laminoplasty and all those studies had shown the same concordant results. These studies concluded that the preoperative CL (C2–C7 Cobb's angle) was correlated with higher T1 slope than the patients with lower T1 slope and there was a significant difference between these two groups.[15-17,22] This can also be explained as "the patients with lower T1 slope tend to have a more kyphotic alignment of cervical spine than those patients of higher T1 slope." However, a higher T1 slope was not only associated with more CL, but also with an increased tendency of LCL

following laminoplasty than the patients with lower T1 slope.[15-17]

These findings can be explained by the following hypothesis [Figure 2]:

- Patients with high T1 slope need more lordotic curvature to maintain horizontal gaze which is provided by the action of posterior neck muscles. This lordotic alignment in patients with high T1 slope provides sagittal balance to cervical spine (compensated) and minimizes the energy expenditure to maintain the weight of head in relation to whole spine. In this case, compensation is defined as when a vertical line drawn from the center of dens at the mid C1 level passes through the C7 body
- Some patients cannot compensate the high T1 slope with the same degree of lordosis due to posterior cervical muscle weakness or compromised spinal canal. In these uncompensated cases of high T1 slope, the weight of the head acts as a continuous kyphotic force on the cervical spine and compromises the cervical sagittal balance. These uncompensated patients have more gravity-oriented facet inclination which further increases the kyphotic alignment of cervical spine
- Patients with low T1 slope needs lower CL to maintain the cervical sagittal balance. Hence, the posterior cervical muscles of these patients need to work less to maintain the CL and to compensate the cervical sagittal balance
- In addition, patients with low T1 slope can have uncompensated cervical spine but the degree of kyphotic force acting on them due to the weight of the head is comparatively less as compared to patients with uncompensated high T1 slope.

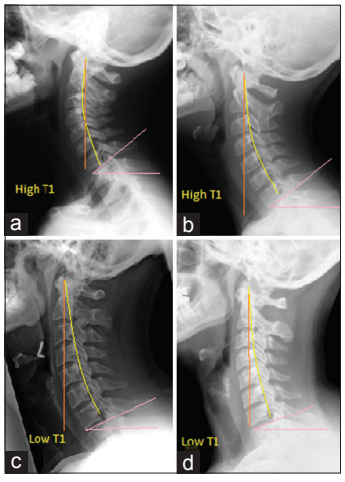

Figure 2: The alignment of cervical spine in patients of high and low T1 slope. (a) Compensated spine with high T1 slope, (b) Uncompensated spine with high T1 slope, (c) Compensated spine with low T1 slope, (d) Uncompensated spine with low T1 slope

In patients with same degree of CL, the cervical sagittal balance can be uncompensated in patients with high T1 slope and it can be compensated even in patients with low T1 slope. Patients can develop postoperative kyphosis and loss of lumbar lordosis after laminoplasty. This can be explained by the forces including the weight of the head acting on the cervical spine.

Various studies on this topic conclude that:

- To maintain the horizontal gaze, cervical alignment required is directly related to the level of T1 slope
- Posterior neck muscles, nuchal ligaments, and the lamina are responsible for maintaining the lordotic alignment of cervical spine[23]
- These structures are in evidently damaged during laminoplasty
- An increase in T1 slope results in greater kyphotic alignment or LCL following laminoplasty.

A study by Lee *et al*.[24] found a relationship between T1 slope and kyphotic alignment change (more than 5° change postoperatively) postlaminoplasty using the receiver operating characteristic curve analysis. As per this study, the cut-off point was found to be 29° using optimal intersection of sensitivity and specificity. This study concludes that patients with T1 slope >29° have more tendency of kyphotic alignment change of more than 5° following laminoplasty than those with T1 slope of <29°. Hence, T1 slope of >29° is considered a risk factor for the development of postoperative kyphosis in patients undergoing laminoplasty.

C2–C7 sagittal vertical axis

C2–C7 sagittal vertical axis (SVA) is an index of cervical sagittal alignment postlaminoplasty. C2–C7 SVA has been shown by many studies to be unrelated to LCL following laminoplasty.[15-17,22] The chief factor predicting LCL in these cases was the preoperative T1 slope of the patient. However, Zhang *et al*.[22] have conducted a study which concluded that C2–C7 SVA was positively correlated with LCL following laminoplasty. According to this study, higher C2–C7 SVA values was associated with more LCL than lower values of C2–C7 SVA though they did not defined any cut off values for C2–C7 SVA. Hence, it is difficult to correlate C2–C7 SVA with LCL following laminoplasty.[15-17,22]

A study conducted by Lin *et al*.[19] have shown that T1 slope and C2–C7 SVA are goof predictors of LCL, in combination. They classified patients into four categories:

- low T1 slope and low C2–C7 SVA
- low T1 slope and high C2–C7 SVA
- high T1 slope and low C2–C7 SVA
- high T1 slope and high C2–C7 SVA.

Among these categories, patients with low T1 slope (≤20°) and large C2–C7 SVA (>22 mm) surprisingly got increased CL or correction of their kyphotic deformity following laminoplasty whereas the other three categories resulted in LCL. This can be explained due to the compensatory effect of whole spine to maintain the position of head in equilibrium, thus maintaining the horizontal gaze.

Higher T1 slope makes the spine vulnerable to kyphotic force hence there is more LCL. Similarly, lower T1 slope patients have more ability for compensation and their cervical spine compensates for the kyphotic tendency after laminoplasty by producing a lordotic alignment of cervical spine. More the length of cervical spine more is the compensation and this is the reason for increased lordosis in patients with low T1 slope and large C2–C7 SVA patients. However, among patients of low T1 slope and small C2–C7 SVA, though there is scope for compensation due to low T1 slope, the limited length of the cervical spine hinders compensation and hence these patients too experience LCL following laminoplasty.[25]

C2–C7 lordosis (cervical lordosis)

C2–C7 lordosis of the spine helps in maintaining the weight of the head on the cervical spine so that horizontal gaze is possible. In patients with high T1 slope, C2–C7 lordosis is more as compared with those of low T1 slope.[26] This high C2–C7 lordosis is necessary in patients with high T1 slope to maintain horizontal gaze and functional quality of the patient. The posterior neck muscles of these patients need to work more to bring lordosis of the cervical spine. Earlier it was believed that more C2–C7 lordosis was a risk factor for the development of kyphosis or LCL in patients undergoing laminoplasty. However, studies have shown that no such relationship exists and C2–C7 lordosis does not predict LCL following laminoplasty.[17]

T1 slope-cervical lordosis

T1 slope has a positive correlation with CL. More the T1 slope; more is the CL. However, the value of T1 slope is influenced by several factors such as

- Posture
- Aging
- Cervical ROM
- Postoperative LCL.[27,28]

Hence, it is usually difficult to establish the relationship between T1 slope and CL. A study by Kim *et al*.[16] described a new index T1 slope minus CL (T1S-CL) to eliminate the above factors in predicting the relationship between T1S and CL. Interestingly, this index T1S-CL was found to have negative correlation with LCL following laminoplasty.[29] As we already know high T1 slope is associated with more LCL following laminoplasty. Higher values of T1-CL indicated an uncompensated cervical spine or an already kyphotic alignment of cervical spine. Hence, a compensated cervical spine (lower value for T1S-CL) with a high value of T1 slope has a potential for more LCL (not frank kyphosis) following laminoplasty.

Cervical lordosis/T1 slope

We already know that CL is positively correlated with T1S. Li *et al*.[20] studied the relation between CL/T1S and cervical alignment following laminoplasty. They divided the patients based on the values of CL/T1S into three categories:

- low-ratio group (bottom 25% of CL/T1S)
- fair-ratio group (middle 50% of CL/T1S) and
- high ratio group (top 25% of CL/T1S).

This study concluded that patients in the high CL/T1S had more kyphotic alignment changes whereas those in the low CL/T1S developed more postoperative kyphosis. Patients having CL/T1S in the fair ratio zone had the most stable cervical sagittal balance with the least incidence of kyphosis. A too high or too low value of CL/T1S destabilizes the cervical sagittal balance as CL does not match with T1 slope to the same degree leading to cervical alignment changes.

Cervical range of motion

Cervical ROM is an important measure to assess the flexibility of cervical spine movements. Lower cervical ROM was considered as a risk factor for the development of postoperative kyphosis following laminoplasty, but studies by Kim *et al*.[17] and Zhang *et al*.[22] have shown no such relationship exists. Hence, cervical ROM is no longer considered as a risk factor for postoperative kyposis.

Neck Tilt

It defines the relative tilt of cervical spine in relation to the sternum. Neck Tilt (NT) has not been found to predict LCL following laminoplasty.[16]

Thoracic kyphosis

Thoracic kyphosis (TK) is directly related with CL.[30] In patients with high CL, TK is more to compensate for the sagittal balance of the spine. In patients undergoing laminoplasty, preoperative TK has a significant difference between the two groups of patients with high and low T1 slope[15] with patients of high T1 slope having more TK and vice-versa. These changes in TK are necessary to compensate for the LCL following laminoplasty to maintain the spinal sagittal balance. However, TK has no relation in predicting LCL following laminoplasty.[15]

Cephalad vertebral level undergoing laminoplasty

Cephalad vertebral level undergoing laminoplasty (CVLL) has received interest in the recent literature as a potential predictor of LCL following laminoplasty. When the CVLL is C4 or below the incidence of postoperative LCL is less as compared to when the CVLL is C3 and above.

The deep extensor muscles are attached to the spinous process of C2 which maintains the cervical lordotic alignment. Preservation of this musculature is necessary to avoid LCL after surgery.[11,31,32] As the distal portion of the lamina of C2 overlaps the cephalad portion of the lamina of C3, any exposure of C3 lamina, whatever small it is, will disturb the extensor musculature attachment of C2. Therefore, during surgeries involving C3, injury to extensor musculature is almost unavoidable leading to increased incidence of LCL following laminoplasty.

C2–C3 disc angle

CL is the sum of the lordotic alignment of individual pairs of cervical vertebra which is important in maintaining the cervical sagittal alignment. The total CL in healthy individual is approximately 42°, out of which approximately 32° is provided by C1–C2 vertebra and 2° is provided by C2–C3 (therefore, approximately 81% of overall CL is provided by C1–C3).[21]

Hence, the upper cervical spine is responsible for providing majority of CL which also makes it susceptible for failure especially in patients of cervical sagittal imbalance and high T1 slope. Also in patients of high C2–C3 angle, additional stress is placed on C1–C2 vertebra to maintain the head in neutral horizontal position.[33,34]

Lee *et al*.[24] have shown that increased C2–C3 angle preoperatively is associated with increased adverse events following laminectomy and posterior fixation which includes kyphosis, pseudoarthrosis, reoperation, adjacent segment disease, and adjacent segment degeneration. The region of C2–C3 is considered as a transitional zone in the cervical spine similar to the cervicothoracic region or the lumbosacral region. The region of cervical spine cranial to C2–C3 till the craniocervical junction is hypermobile allowing for more freedom of movement than any other part of cervical spine. The region below C2–C3 is also mobile but not to the same extent as the region cranial to it. Therefore, during surgical planning of cervical spine it is reasonable to consider extending fusion constructs to C2 level, thereby crossing the transitional zone especially in patients of high C2–C3 angle and positive cervical sagittal balance to reduce the postoperative adverse effects. Similar technique is used in other junctional regions of spine wherein the constructs if extended beyond the junctional regions during surgeries have reduced failure rates.[35]

Dynamic extension reserve

A study by Sharma *et al*.,[36] has shown dynamic extension reserve (DER) as an independent predictor of LCL following cervical laminoplasty. The spinous process mucle ligament complex (SPMLC) plays and an important role in maintaining the cervical sagittal balance and DER determines the contraction reserve of these SPMLC. Higher DER means the contraction reserve of is more which can compensate for LCL following laminoplasty. Patients having lower DER have low preoperative contraction reserve of SPMLC resulting in higher incidence of LCL as the SPMLC among them is further damaged by laminoplasty.

CONCLUSIONS

Cervical lordotic alignment is important in maintaining cervical sagittal balance which ultimately is responsible for global spinal sagittal balance and horizontal gaze. Several factors responsible for maintaining the cervical sagittal balance are disturbed during laminoplasty leading to loss of lordotic alignment of cervical spine and functional disability. Following important conclusions can be drawn about cervical sagittal balance:

- Patients with high T1 slope have more lordotic alignment of cervical spine preoperatively. They also have more chances of LCL following laminoplasty
- C2–C7 SVA has no role in predicting LCL following laminoplasty though patients with low T1 slope (≤20°) and high C2–C7 SVA (>22 mm) had correction of kyphotic deformity following laminoplasty
- C2–C7 lordosis, NT, cervical ROM, and TK has no role in predicting LCL
- Lower value of T1S-CL and CL/T1S has more incidence of developing LCL: following laminoplasty
- Starting laminoplasty at C4 level reduces the risk of LCL following laminoplasty
- Patients having low DER and high T1 slope have higher incidence of LCL following laminoplasty as compared with those having low T1 and high DER.

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Conflicts of interest

There are no conflicts of interest.

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