The effect of disruption of the repaired nuchal ligament on clinical outcomes after posterior cervical spine surgery: A retrospective comparative study

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ABSTRACT

Objective: This study aimed to investigate whether disruption of the repaired nuchal ligament (NL) affects clinical outcomes following posterior cervical spine surgery.

Methods: This retrospective study included 101 patients (65 males, 36 females) who underwent posterior cervical spine surgery, 69 of whom received laminoplasty (LP), and 32 posterior decompression and fusion (PDF). The NL was split during the surgical approach and repaired at the time of wound closure. The frequency and spinal levels of NL disruption at one month, six months, and one year postoperatively were evaluated on mid-sagittal and axial magnetic resonance images. Postoperative axial symptoms, Neck Disability Index, T1 slope, flexion and extension angle, C2-C7 lordotic angle, and decrease rate of C2-C7 range of motion (ROM) were examined at six months and/or one year postoperatively. Based on the NL disruption levels, the patients were divided into the upper group (C2-C5), lower group (C6-T1), and non-disruption group.

Results: Although the lower group contained patients with NL disruption (10%) after LP at final follow-up, all PDF patients belonged to the non-disruption group. For the LP patients, the postoperative axial symptoms, Neck Disability Index, T1 slope, flexion and extension angle, and C2-C7 lordotic angle did not significantly differ between the lower and non-disruption groups; however, the rate of C2-C7 ROM decrease in the lower group (48%) was considerably larger than that in the non-disruption group (37%) after LP.

Conclusion: Evidence from this study has shown that postoperative disruption of the repaired NL has no significant effect on postoperative axial symptoms and C2-C7 alignment, but it can affect the rate of decrease in C2-C7 ROM after LP.

Level of Evidence: Level III, Therapeutic Study

Introduction

Preservation or repair of the nuchal ligament (NL) is clinically important for preventing postoperative axial symptoms and maintaining cervical alignment and range of motion (ROM) after posterior cervical spine surgery. To decrease axial symptoms after cervical laminoplasty (LP), the posterior approach with reconstruction of the posterior ligamentous complex with extensor muscles was developed.1 Tension-band LP with complete preservation of the NL was also developed to retain good postoperative ROM of the cervical spine.2 Preservation of the NL at the lower cervical spine reportedly prevents malalignment and axial pain after LP.34 The characteristics of the NL have been reported in basic studies. The NL is more densely and closely bound to the C7 spinous process, and the NL at C6 and C7 is reportedly attached to 4 major muscles.5 Furthermore, a cadaveric anatomical study showed that the NL is attached to not only the C7 spinous process but also the longer C6 spinous process,6 while a biomechanical study revealed that the NL restrains cervical spine flexion.7 Therefore, it may be ideal to preserve or repair the NL during posterior cervical spine surgery, especially at the lower cervical spine.

During posterior cervical spine surgery, the NL is commonly split along its center and repaired carefully with nonabsorbable sutures at the time of wound closure. However, the authors have frequently encountered patients whose repaired NL was disrupted on magnetic resonance imaging (MRI), and the progress of the restoration of the repaired NL is unknown. Furthermore, how much influence the disruption of the repaired NL, especially at the lower cervical spine, actually has on the clinical outcomes after posterior cervical spine surgery (such as axial symptoms, alignment, and/or ROM) is unclear.

This retrospective study was performed to clarify the progress of the restoration of the repaired NL and investigate whether disruption of the repaired NL affects the outcomes after posterior cervical spine surgery, including axial symptoms, alignment, and ROM of the cervical spine.

Materials and Methods

Patients

The present study included 101 patients, 69 of whom had undergone LP and 32 who had undergone posterior decompression and fusion (PDF). Informed
consent was obtained from the parents of the patients. This study was approved by the institutional ethics committee according to the 1964 Helsinki declaration (approval number 30-09), and informed consent was obtained from all participants. All patients had cervical myelopathy. The neurologically symptomatic level was diagnosed by evaluating the preoperative spinal cord evoked potential, which was measured after electrical stimulation to the spinal cord as described by Tani et al.\(^9\) After administration of local anesthesia, a stimulating electrode and recording electrode with platinum tips were introduced into the dorsal epidural space at the lower thoracic level and the C3 level, respectively. Recordings were obtained simultaneously at the C3, C3/4, C4, C4/5, C5, C5/6, C6, C6/7, C7, and C7/T1 levels. Each test set comprised an adding frequency of 50 times, with a stimulation frequency of 30 Hz and a stimulus intensity of 7-10 mA. A level was defined as neurologically symptomatic when the negative peak increased at the immediately caudal level and the negative peak decreased at the immediately cranial level.\(^10\) Table 1 shows the distributions of the neurologically symptomatic levels. Patients with multiple neurologically symptomatic levels of the spinal cord were counted respectively.

Laminoplasty was performed for patients with severe cervical spondyloytic myelopathy (CSM) without malalignment and K-line (+) ossification of the posterior longitudinal ligament (OPLL). Posterior decompression and fusion was used for patients with K-line (−) OPLL in the flexed-neck position\(^6\) or CSM with malalignment. Double-door LP was performed in 47 patients with CSM and 22 with OPLL from 2011 to 2017, while PDF was performed in 9 patients with CSM and 23 with OPLL from 2013 to 2017. All patients who completed 1 year of follow-up were included (follow-up rate: 92%). The patients who had undergone LP comprised 44 men and 25 women with an average age of 61 years at the time of surgery (range: 34-87 years). For those who underwent LP, the mean Japanese Orthopaedic Association score significantly improved from 10.7 points to 13.3 points at 1 year postoperatively \((P < .01)\). For those who underwent PDF, the mean Japanese Orthopaedic Association score significantly improved from 9.8 points preoperatively to 13.1 points at 1 year postoperatively \((P < .01)\).

### Table 1. Distributions of neurologically symptomatic levels

| Level       | C3/4 | C4/5 | C5/6 | C6/7 | C7/T1 |
|-------------|------|------|------|------|-------|
| Number in LP group, n = 60 | 20 (23) | 29 (33) | 30 (34) | 8 (9) | 1 (1) |
| Number in PDF group, n = 32 | 10 (26) | 9 (25) | 15 (42) | 2 (5) | 0 (0) |

Data are presented as n (%). Duplicate numbers are present because some patients had multiple neurologically symptomatic levels. LP, laminectomy; PDF, posterior decompression and fusion.

The disrupted level of the NL was evaluated on T2-weighted mid-sagittal and axial MRI views, with broken continuity of the NL defined as disruption of the NL (Figure 2). The disrupted level of the NL was evaluated on T2-weighted mid-sagittal MRI and was used to divide patients into the upper group (C2-S) (Figure 2b), lower group (C6-T1) (Figure 2c), and the non-disruption group (Figure 2a). Images were taken using XTREX VIEW (J-MAC System, Sapporo, Japan).

### Evaluation of nuchal ligament rupture

Follow-up MRI was performed routinely at 1 month, 6 months, and 1 year postoperatively in all patients. The disruption of the NL was evaluated using T2-weighted mid-sagittal and axial MRI views, with broken continuity of the NL defined as disruption of the NL (Figure 2). The disrupted level of the NL was evaluated on T2-weighted mid-sagittal MRI and was used to divide patients into the upper group (C2-S) (Figure 2b), lower group (C6-T1) (Figure 2c), and the non-disruption group (Figure 2a).

### Distribution of groups and clinical outcomes

The distributions of the 3 groups were investigated at 1 month, 6 months, and 1 year postoperatively for each surgical method. The Visual Analog Scale was used to evaluate axial symptoms, including neck pain, neck stiffness, and suprascapular stiffness. These 3 types of axial symptoms were compared among the groups at 6 months and 1 year postoperatively for each surgical method. The Neck Disability Index (NDI) was also compared among the groups at 6 months and 1 year postoperatively for each surgical method.

### Operative technique and postoperative treatment

The center of the NL was split using electrocautery during the surgical approach and repaired as much as possible using nonabsorbable sutures at the time of wound closure, regardless of the surgical method. All patients underwent C3 laminectomy with complete preservation of the semispinalis cervicis insertion at C2.\(^13\) The long spinal processes at C6 and C7 were cut so that they aligned with the length of the spinous processes at C4 and C5. Laminoplasty of C4-C7 was performed using hydroxyapatite spinous process spacers.\(^12\) During PDF, pedicle screws were inserted in the bilateral C2, C7, and T1 pedicles, preserving the muscles inserted at C2; the lateral mass screws at C4-6 or the C5 pedicle screws were used as mid-cervical anchors, and local bone grafting was performed from C2/3 to C7/T1 in all patients.\(^15\) At the time of C2 pedicle screw insertion, the insertion point at the muscle interval between the oblique capitii inferior and semispinalis cervicis inserted into C2 was exposed using a spatula, bipolar cautery, and medical scissors so that the muscles inserted at C2 were preserved completely (Figure 1). Care was taken to caution the outside venous plexus of the C2 lamina. The lateral edge of the cervical spinal canal of C2 (i.e., the inside of the pedicle) could be touched and confirmed using a spatula at the C1/2 facet joint. Postoperative immobilization with a collar was not performed in any patient, regardless of the surgical method.

### Highlights

- The integrity of the nuchal ligament (NL) is thought to have an important role for preventing postoperative axial symptoms and maintaining cervical alignment and range of motion after posterior cervical spine surgery; however, this relationship has not been clarified.
- This study was aimed to help clarify the progress of the restoration of the repaired NL and investigate whether disruption of the repaired NL affects the outcomes of posterior cervical spine surgery.
- The findings of this study suggest that postoperative disruption of the repaired NL has no effect on postoperative axial symptoms and C2-C7 alignment, however it does affect the rate of decrease in C2-C7 ROM after LP.
Radiological evaluations
Radiological examinations were performed in the patients who underwent LP. All radiographs were taken in the standing position. The T1 slope was measured on cervical radiographs as the angle between a horizontal line and the superior end plate of T1. The flexion and extension angles of the C2 and C7 vertebral bodies were obtained on lateral radiographs in the flexion and extension positions. The lordotic angle at C2-C7 was measured on a lateral radiograph of a neutral view of the cervical spine using the posterior tangents of the C2 and C7 vertebral bodies. The ROM at C2-C7 was measured on lateral flexion and extension radiographs of the cervical spine using the posterior tangents of the C2 and C7 vertebral bodies. The postoperative decrease rate of the ROM at C2-C7 at 1 year after LP was calculated using the following formula: decrease rate (%) = (1 − postoperative ROM/preoperative ROM) × 100. The lordotic angle at C2-C7 and the decrease rate of the ROM at C2-C7 were compared among the groups at 1 year after LP. All radiographs were measured using XTREX VIEW (J-MAC System), which was accurate to 0.01°.

Statistical analysis
Statistical analyses were conducted using the Mann–Whitney U test, Chi-squared test, and Wilcoxon’s signed-rank test. Differences with a P-value of <.05 were considered statistically significant.

Results
Changes in group distributions over time
The distributions of the 3 groups within each surgery method are shown in Figure 3 and Table 2. After LP, the respective distributions in the upper, lower, and non-disruption groups were 11%, 64%, and 25% at 1 month; 0%, 17%, and 83% at 6 months; and 0%, 10%, and 90% at 1 year. After PDF, the respective distributions in the upper, lower, and non-disruption groups were 0%, 69%, and 31% at 1 month; 0%, 3%, and 97% at 6 months; and 0%, 0%, and 100% at 1 year. Although there were still patients with NL disruption (10%) in the lower group after LP at final follow-up, all patients who had undergone PDF belonged to the non-disruption group at final follow-up.
Axial symptoms and the Neck Disability Index
The results of the comparison of axial symptoms between the lower and non-disruption groups after surgery are shown in Figures 4 and 5. The Visual Analog Scale score of all 3 types of axial symptoms (neck pain, neck stiffness, and suprascapular stiffness) did not differ between the lower and non-disruption groups at 6 months and 1 year after LP. One patient in the PDF group had NL disruption at 6 months after surgery, and no patients had NL disruption at 1 year after surgery; these results could not be compared statistically. Therefore, postoperative disruption of the repaired NL had no effect on postoperative axial symptoms after PDF. The results of the comparison of the NDI between the lower and non-disruption groups after surgery are shown in Figures 6 and 7. The NDI did not differ between the lower and non-disruption groups at 6 months and 1 year after LP. The postoperative axial symptoms and NDI of patients who had undergone PDF could not be compared between the groups because all patients who underwent PDF belonged to the non-disruption group at final follow-up.

Sagittal alignment and range of motion at C2-C7
The results of the comparison of the T1 slope between the LP and PDF groups before surgery and at 6 months and 1 year after surgery are shown in Figure 8. The preoperative and postoperative (at 6 months and 1 year) T1 slopes were 24.9°, 25.9°, and 26.0° in the LP group and 21.9°, 25.5°, and 25.4° in the PDF group, respectively. There was no significant difference between the LP and PDF groups at each time point. Figure 9 shows the preoperative and postoperative flexion and extension angles between the lower and non-disruption groups in the LP group. There was no significant difference in the flexion or extension angle, but the flexion angle tended to change from before to after surgery. The results of the comparison of the lordotic angle and decrease rate of the ROM at C2-C7 between the lower and non-disruption groups at 1 year after LP are shown in Figure 10a and b, respectively. The preoperative and postoperative lordotic angle at C2-C7 was 11.7° and 21.4°, respectively. The mean lordotic angle at C2-C7 at 1 year after LP was similar in the lower group (21.2°) and non-disruption group (21.3°). The preoperative and postoperative ROM at C2-C7 was 43.9° and 27.6°, respectively. The mean decrease rate of the ROM at C2-C7 was significantly higher in the lower group (48%) than in the non-disruption group (33%) at 1 year after LP (P = .01). The sagittal alignment and decrease rate of the ROM in patients who had undergone PDF could not be compared between the groups because all patients who underwent PDF belonged to the non-disruption group at final follow-up.

| Table 2. Distributions of NL-Disrupted level |
|---------------------------------------------|
| Number in LP group, n = 69                  |
| 1 month postoperatively                     |
| Upper Group                                |
| Lower Group                                |
| Non-disruption Group                       |
| 8 (11)                                     |
| 45 (64)                                    |
| 18 (25)                                    |
| 6 months postoperatively                    |
| 0 (0)                                      |
| 12 (17)                                    |
| 57 (83)                                    |
| 1 year postoperatively                      |
| 0 (0)                                      |
| 6 (9)                                      |
| 63 (91)                                    |
| Number in PDF group, n = 32                |
| 1 month postoperatively                     |
| 0 (0)                                      |
| 22 (69)                                    |
| 10 (31)                                    |
| 6 months postoperatively                    |
| 0 (0)                                      |
| 1 (1)                                      |
| 31 (97)                                    |
| 1 year postoperatively                      |
| 0 (0)                                      |
| 0 (0)                                      |
| 32 (100)                                   |

Data are presented as n (%). Duplicate numbers are present because some patients had multiple disrupted levels of the NL in the LP group at 1 month postoperatively. NL, nuchal ligament; LP, laminoplasty; PDF, posterior decompression and fusion.
Discussion

In the present study, 67%-69% of patients had disruption of the NL at the lower cervical spine at 1 month after either LP or PDF. Although some patients still had NL disruption (10%) in the lower group at 1 year after LP, all patients who had undergone PDF belonged to the non-disruption group at 1 year after surgery. In those who underwent LP, postoperative disruption of the repaired NL at the lower cervical spine had no effect on postoperative axial symptoms, the NDI, or alignment of the cervical spine; however, the mean decrease rate of the ROM at C2-C7 was significantly higher in the lower than in the non-disruption group at 1 year after LP.

The details regarding the progress of the restoration of the disruption of the repaired NL are unknown. Johnson et al. examined the connective tissue architecture of the human NL by stereomicroscopic examination of plastinated slices. They reported that the tendons from the trapezius, splenius capitis, rhomboideus minor, and serratus posterior superior join at the midline as a body of dense connective tissue before attaching directly to the C7 spinous process; the NL is a triangular body of dense connective tissue at C4, and dense connective tissue fibers pass ventrally to the tips of the C5 spinous process. Therefore, disruption of the lower cervical spine might occur because of the strong postoperative strain applied to both sides by the body of connective tissue that connects the 4 muscles described above. Although some patients still had a ruptured NL (10%) in the lower group at 1 year after LP, all patients who had undergone PDF belonged to the non-disruption group at 1 year postoperatively. The markedly reduced neck mobility after PDF is a possible reason why the NL that was disrupted in 69% of patients at 1 month postoperatively had spontaneously repaired by 1 year postoperatively.

Hosono et al. reported that the incidence of axial pain at 1 year postoperatively was significantly greater after C3-7 LP than after C3-6 LP. Therefore, the disrupted NL, especially at the lower cervical spine, might lead to axial symptoms after posterior cervical spine surgery involving C2-C7. The authors thus considered that NL repair is
important after posterior cervical surgery. In the present study, how-
ever, the axial symptoms were similar between the lower and non-
disruption groups. The good neck conditions achieved by complete
preservation of the semispinalis cervicis inserted at C2 in the pres-
ent case series might have prevented the patients from experienc-
ing axial pain due to the disruption of the NL at the lower cervical
spine.11,13

In double-door LP, the split spinous process at C6 and C7 may inter-
fer with midline repair of the membranous portion of the NL. In
this LP and PDF, the spinous processes at C6 and C7 are excised so
that they are aligned with the length of C4 and C5; therefore, they do
not interfere with ligament repair. Ono et al6 used 35 Japanese adult
cadavers (21 male, 14 female) with no history of cervical spine sur-
gery for an anatomical study. The lengths of the C6 and C7 spinous
processes were measured on sagittal CT images, and the C6:C7 ratio
was calculated. When the C6:C7 ratio is >0.8, it is very likely that
the NL attaches to the C6 spinous process. Therefore, the NL can be
strongly sutured because it acts as a hard anchor, especially at C6 and
C7. In another study, Leung et al16 examined the tensile strength
and qualitative histology of bone-to-bone, bone-to-tendon (BT), and
tendon-to-tendon (TT) healing in Achilles tendon complex models
in 47 adolescent goats. They reported that the failure load was sig-
nificantly lower in the BT than TT group at 12 weeks and that the
morphological characteristics showed faster remodeling in the bone-
to-bone and TT groups than in the BT group. However, TT repair
of the NL may be ideal during posterior cervical spine surgery. In
several patients, the NL was disrupted at the lower level of the cervi-
cal spine after surgery. An improved NL repair technique is needed,
especially at the lower cervical spine, because the present study
showed that the decrease rate of the C2-C7 ROM was significantly
higher in the lower than in the non-disruption group at 1 year after
LP. The NL is formed by fine horizontal aponeurotic fibers from the
trapezius, rhomboideus minor, and serratus posterior minor, along
with the splenius capitus at C6 and C7.5 Thus, the NL should not be
split using electrocautery because this may destroy the fine aponeu-
rotic fibers.

Measurement of the T1 sagittal angle may be useful in evaluating
sagittal balance because this angle is most strongly correlated with
the dens plumb line.14 In this series, the T1 slope was not significantly
different between the LP and PDF groups. Likewise, there was no sig-
nificant difference between before and after surgery. Therefore, the
T1 slope likely has a small influence on the postoperative cervical
spine alignment. The cervical and thoracic sagittal alignment param-
eters such as the C2-C7 sagittal vertical axis, cervical lordosis, and
T1 slope are parameters worth considering because they can lead to
poor quality of life and axial neck pain after LP.15 In this series, the
sagittal balance did not appear to affect axial symptoms or the NDI.

Preservation of the NL during posterior cervical spine surgery
reportedly maintains good postoperative ROM of the cervical spine.
Tsuzuki et al2 analyzed 102 patients at 3 years after tension-band LP
and reported that the incidence of good preservation of preopera-
tive movement between C2 and C7 was 79% in patients with CSM
and 67% in those with OPLL. In the present study, the decrease
rate of C2-C7 ROM was significantly higher in the lower group
(48%) than in the non-disruption group (33%) at 1 year after LP. The
NL at C6 and C7 is reportedly attached to the trapezius, rhomboi-
deus minor, serratus posterior superior, and splenius capitus.5 The
fact that the trapezius and splenius act as extensors may explain
why the decrease in postoperative ROM was greater in the lower
group than in the non-disruption group after LP. There was no sig-
nificant difference in either the flexion or extension angle before
and after surgery between the lower and non-disruption group.
Takeshita et al7 reported that resection of the NL increased the
flexion ROM and decreased stiffness in flexion. In the present series, the NL was tightly sutured at the time of closure, and postoperative MRI showed that it was split in the middle of the NL. Therefore, the NL probably has not lost its role as an anchor for the extensor muscle. Because of the small number of patients (n=6, 10%) in the lower group at 1 year after LP, there was no significant difference in the extension angle at 1 year after LP. Therefore, a larger number of patients are needed to investigate the clinical outcomes and radiological evaluations by surgical procedure.

The present study had 2 main limitations. First, the study population was small. Second, the follow-up period was short. Long-term monitoring is needed to determine whether the patients in the lower group at 1 year after LP change to the non-disruption group over time. In conclusion, although cases of NL rupture (10%) remained in the lower group at 1 year after LP, all PDF cases belonged to the non-disruption group. Although postoperative disruption of the repaired NL had no effect on postoperative axial symptoms and C2-C7 alignment, it did affect the rate of decrease in C2-C7 ROM after LP.

Ethics Committee Approval: This study was approved by the institutional ethics committee of Odate Municipal General Hospital according to the 1964 Helsinki declaration (approval number 36-09).

Informed Consent: Informed consent was obtained from the parents of the patients.

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