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ORIGINAL ARTICLE

Bone union and remodelling of the non-ossified segment in thoracic ossification of the posterior longitudinal ligament after posterior decompression and fusion surgery

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Abstract
Purpose The motion at the non-ossified segment of the ossification of the posterior longitudinal ligament (OPLL) is thought to be highly correlated to aggravation of symptoms of myelopathy. The rationale for posterior decompression with instrumented fusion (PDF) surgery is to limit the motion of the non-ossified segment of OPLL by stabilization. The purpose of the present study was to elucidate the course of bone union and remodelling of the non-ossified segment of thoracic OPLL (T-OPLL) after PDF surgery.
Methods A total of 29 patients who underwent PDF surgery for T-OPLL were included in this study. We measured the thickness of the OPLLs by determining the thickest part of the OPLL in the sagittal multi-planer reconstruction CT images pre- and post-operatively. Five experienced spine surgeons independently performed CT measurements of OPLL thickness twice. Japanese Orthopaedic Association score for thoracic myelopathy was measured as clinical outcome measure.
Results Non-ossified segment of OPLLs fused in 24 out of 29 (82.8 %) patients. The average thickness of the OPLL at its thickest segment was 8.0 mm and decreased to 7.3 mm at final follow-up. The decrease in ossification thickness was significantly larger in the patients who showed fusion of non-ossified segments of OPLL compared with that in the patients did not show fusion. There was no significant correlation between the clinical outcome and the decrease in thickness of the OPLLs.
Conclusion The results of this study showed that remodelling of the OPLLs, following fusion of non-ossified segment of OPLLs, resulted in a decreased OPLL thickness, with potential for a reduction of spinal cord compression.

Keywords OPLL · Bone union · Fusion surgery · Remodelling

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Introduction

In recent years, multi-slice computed tomography (CT) has exhibited added advantages for musculoskeletal imaging, including volumetric imaging and the ability to acquire multi-planar reconstructions (MPR). CT MPR images make it possible to obtain a precise observation of fine structures in an arbitrary plane that can be achieved following the acquisition of data from a single scan without the need for gantry angulation. Similarly, CT MPR images have been widely used to assess bony structures in the field of spinal surgery. By the acquisition of CT MPR sagittal images, the precise morphology of ossification of the posterior longitudinal ligament (OPLL) may be assessed, as opposed to via plain radiograms or conventional axial CT images, which have distinct limitations [1, 2]. CT MPR sagittal images of OPLL can reveal a non-ossified segment of the ossification at the thickest segment of ossification foci, even if the ossification seems to be continuous when classified by plain radiogram. The motion at the non-ossified segment of the OPLL is thought to be highly correlated to aggravation of myelopathy [3]. Therefore, posterior decompression with instrumented fusion (PDF) has been indicated as one of the first-line treatment choice for patients with thoracic OPLL (T-OPLL), instead of posterior decompression alone [4]. The rationale for PDF surgery is to limit the motion of the non-ossified segment of OPLL by stabilization [5, 6].

Previous report revealed the bony fusion of non-ossified segment of OPLLs after PDF surgery. Following bony fusion, bone remodelling was also occasionally observed, which resulted in a reduction in the thickness of the ossification and an alteration from a sharp/angular morphology to one that was blunt [7].

The purpose of the present study was to elucidate the course of bone fusion and remodelling of the non-ossified segment of T-OPLL after PDF surgery.

Patients and methods

Study design

This was a retrospective cohort study.

Patient population

This study included patients who underwent PDF surgery for T-OPLL from September 2001 to May 2012 at our institute. A total of 29 patients (male 16 cases, female 13 cases) were included in this study. The average age of patients at the time of surgery was 53.4 years (range 22–74 years). The average number of fused segments was 8.1 (range 5–12 segments). The mean follow-up period was 68.8 months (range 17–147 months).

Surgical procedure

The patients underwent laminectomy at the spinal cord compression levels followed by posterior instrumented fusion with pedicle screw and rod system. The fused segments were two or three levels above and below the levels of laminectomy. Postero-lateral autologous bone graft was performed with local bone including resected spinous processes and laminae. We applied the posterior in situ fusion without correction of the spinal alignment.

CT image analysis

We assessed the non-ossified segment of OPLLs and measured the thickness of OPLLs at the thickest segment using pre-operative sagittal MPR images and post-operative follow-up CT scans. The CT images were acquired by continuous helical scanning (Aquilion 3; Toshiba Medical Systems, Tochigi, Japan) and sagittal plane reconstructed images were obtained (Vitrea software; Toshiba Medical Systems). Three consecutive sagittal images were acquired at 1 mm intervals, including a mid-sagittal slice; these were analysed for each patient.

Patients' OPLLs were classified into *linear*, *beaked*, *continuous waveform* and *continuous cylindrical* types by their morphology according to the previous reports [8, 9], but with a slight modification; we added the *circumscribed* type, identified when ossification was localised at the level of the disc without continuation between vertebrae (Fig. 1). Non-ossified segment of the ossification foci of the affected PLL was defined as the discontinuation of ossification as detected by CT reconstructed MPR images acquired in the sagittal plane. All patients in this series had non-ossified segment of ossification foci. We measured the thickness of the OPLLs by determining the thickest part of the OPLL in the three sagittal slices acquired during CT scanning. Five experienced spine surgeons independently performed CT measurements of OPLL thickness on 2 separate occasions of which interval was at least 3 days.

Clinical outcome measure

Our assessments were based on the Japanese Orthopaedic Association (JOA) score for cervical myelopathy, although we excluded the upper extremity motor and sensory functional scores as clinical outcome measures. The maximum JOA score is 11 points (Table 1).

We compared thoracic (T) JOA scores pre- and post-operatively, and the rate of recovery was computed by the following method: obtained points (i.e., post-operative JOA score – pre-operative JOA score)/pre-operative defect points (i.e., maximum score [11 points] – pre-operative JOA score) [10].

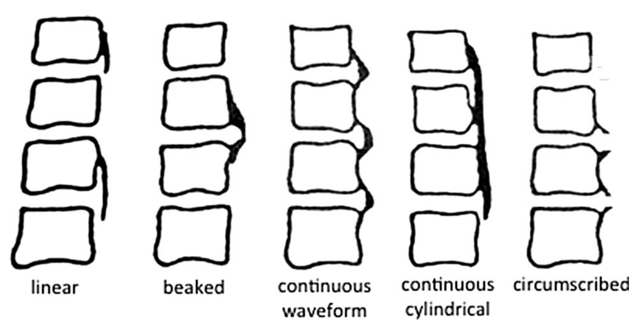

Fig. 1 The classification of thoracic OPLL by its morphology. Patients' OPLLs were classified into *linear*, *beaked*, *continuous waveform* and *continuous cylindrical* types by their morphology according to the previous reports, but with a slight modification; we added the *circumscribed* type, identified when ossification was localised at the level of the disc without continuation between vertebrae

Table 1 Japanese Orthopaedic Association score for thoracic myelopathy

Lower extremity motor function	
Unable to stand and walk by any means	0
Unable to walk without a cane or other support on a level	1
Capable of walk without support on a level but needs support on stairs	2
Capable of walk with clumsiness	3
Normal	4
Sensory function	
Trunk	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Lower extremity	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Bladder function	
Urinary retention or incontinence	0
Sense of retention or dribbling or thin stream or incomplete continence	1
Urinary retardation or pollakiuria	2
Normal	3

Statistical analysis

Inter-rater reliability and intra-rater reliability were expressed as R^2 value, both of which were assessed by expected mean square method and restricted maximum likelihood method, respectively. Inter-rater and intra-rater reliability determined with R^2 values were classified according to the previous report [11]: >0.81, almost perfect; 0.61–0.80, substantial; 0.41–0.60, moderate; 0.21–0.40, fair and 0–0.20, slight. Thickness of OPLL was compared between pre-operative and at final follow-up using paired t test. p value was determined as significant when it was smaller than 0.05. The correlation between the clinical outcome measure and the change in OPLL thickness was determined by Pearson's correlation coefficient test. The correlation between the follow-up period and the change in OPLL thickness was determined by Pearson's correlation coefficient test. All of the statistical analyses were performed with statistical software JMP version 10 (SAS Institute Japan, Tokyo, Japan).

Results

The morphology of the ossification was classified as follows: beaked type (5 cases), continuous waveform type (9 cases), continuous cylindrical type (12 cases) and circumscribed type (3 cases). Non-ossified segment of OPLLs fused in 24 out of 29 (82.8 %) patients over an average duration of 17.2 months (6–36 months) after the surgery. For 3 out of 5 (60 %) patients who exhibited no fusion of their non-ossified segment, the OPLL classification type was *circumscribed*.

Inter-rater reliability was calculated as substantial ($R^2 = 0.68$) and intra-rater reliability was calculated as moderate ($R^2 = 0.58$).

Preoperatively, the average thickness of the OPLL at its thickest segment was 8.0 mm (range 5.6–11.0 mm), decreased to 7.3 mm (range 5.3–9.0 mm) at final follow-up. The average decrease in thickness of OPLL was 0.8 mm (range 0.1–2.7 mm). There was significant difference between pre- and post-operative OPLL thickness (Fig. 1, $p = 0.004$; Fig. 2a–d). The average reduction of OPLL thickness in the patients who showed bony fusion of non-ossified segment was 1.2 mm (0.1–2.7 mm), whereas that in the patients who did not show bony fusion of non-ossified segment was 0.3 mm (0.1–0.5 mm). There was significant difference in reduction of OPLL thickness between the patients with and without bony fusion of non-ossified segment of OPLL ($p = 0.032$). There was no significant correlation between the clinical outcome and the decrease in thickness of the OPLLs. There was also no significant correlation between the follow-up period and the decrease in thickness of the OPLLs.

Discussion

The results of this study showed that remodelling of the OPLLs, following fusion of non-ossified segment of OPLLs, resulted in a decreased OPLL thickness, with potential for a reduction of spinal cord compression.

The precise mechanism underlying the reduction of OPLL thickness after PDF surgery is unclear. Our hypothesis is that the motion at the non-ossified segment stimulates the local thickening of the OPLL, therefore stabilization can reduce the ossification foci, of which mechanism might be similar to the reduction of protruded bony fragments in spinal canal of burst fracture cases after stabilization [12]. The other possible explanation is the pulsation of the thecal sac might reduce the size of ossification foci, of which mechanism is similar to the reduction of ossification of the ligamentum flavum after floating decompression procedure with instrumented fusion [13].

The present results may provide a possible rationale for PDF surgery to reduce the risk of the neurological deterioration by the motion at the residual anterior spinal cord compression by OPLL. In the past it was reported that neurological recovery after PDF surgery is gradual and peaks 9 months, on average, after surgery [14]. Our results

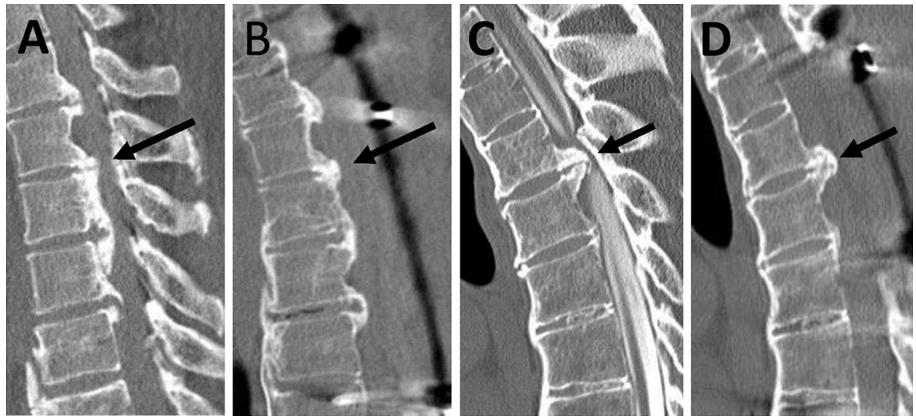

Fig. 2 Representative cases showing continuous waveform type OPLL (**a**, **b**) and beaked type OPLL (**c**, **d**). There was non-ossified segment at the thickest segment of OPLL (**a**, **c**; *arrows*). Several years after surgery, fusion of non-ossified segment and decrease in thickness of OPLL was observed (**b**, **d**; *arrows*)

showed that healing of non-ossified segment of OPLLs occurred 17 months, on average, after surgery. OPLL micro-motion after surgery may be a factor that slows neurological recovery.

The clinical significance of the bony fusion of a non-ossified segment of OPLL is still unclear. However, we speculate that motion occurring at a non-ossified segment of OPLL might contribute to repetitive minor damage to the spinal cord which could result in neurological deterioration. Thus, limiting motion in the compressed segment of the spinal cord is crucial for neurological recovery. According to the previous reports, neurological recovery achieved by PDF surgery was equivalent compared with the other surgical procedures, even though the spinal cord compression caused by the OPLL foci still remains after PDF surgery, suggesting that stabilization at the spinal cord compressed site is definitely important [5, 9, 12]. The present study revealed that bone union of the non-ossified segment of the ossification foci after PDF surgery, possibly providing additional stability to compressed spinal cord.

If remodelling is able to reduce the thickness of an OPLL, early fixation surgery can be beneficial for patients who show subclinical, or only mild myelopathy with a thickening OPLL and a disruption at the associated ossification foci. Future investigation is needed to clarify this point.

Conclusions

Non-ossified segment of OPLLs showed evidence of bony fusion, remodelling, and a decrease in thickness after PDF surgery for T-OPLL.

Conflict of interest None.

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