A Systematic Review of Classification Systems for Cervical Ossification of the Posterior Longitudinal Ligament

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Abstract

Design: Systematic review.
Objective: To conduct a systematic review to (1) summarize various classification systems used to describe cervical ossification of the posterior longitudinal ligament (OPLL) and (2) evaluate the diagnostic accuracy of various imaging modalities and the reliability of these classification systems.
Methods: A search was performed to identify studies that used a classification system to categorize patients with OPLL. Furthermore, studies were included if they reported the diagnostic accuracy of various imaging modalities or the reliability of a classification system.
Results: A total of 167 studies were deemed relevant. Five classification systems were developed based on X-ray: the 9-classification system (0.60%); continuous, segmental, mixed, localized or focal, circumscribed and others (92.81%); hook, staple, bridge, and total types (2.40%); distribution of OPLL (2.40%); and K-line classification (4.19%). Six methods were based on computed tomography scans: free-type, contiguous-type, and broken sign (0.60%); hill-, plateau-, square-, mushroom-, irregular-, or round-shaped (5.99%); rectangular, oval, triangular, or pedunculate (1.20%); centralized or laterally deviated (1.80%); plank-, spindle-, or rod-shaped (0.60%); and rule of nine (0.60%). Classification systems based on 3-dimensional computed tomography were bridging and nonbridging (1.20%) and flat, irregular, and localized (0.60%). A single classification system was based on magnetic resonance imaging: triangular, teardrop, or boomerang. Finally, a variation of methods was used to classify OPLL associated with the dura mater (4.19%).
Conclusions: The most common method of classification was that proposed by the Japanese Ministry of Health, Labour and Welfare. Other important methods include K-line (+/-/–), signs of dural ossification, and patterns of distribution.

Keywords
ossification of the posterior longitudinal ligament, K-line classification, dural ossification, classification systems, reliability

Introduction

Ossification of the posterior longitudinal ligament (OPLL) is defined as ectopic bone formation within the posterior longitudinal ligament.¹ OPLL can result in spinal canal or foraminal narrowing, cause myelopathy or radiculopathy, and increase the risk of spinal cord injury following a traumatic event. It is a multifactorial, degenerative disease in which both environmental and genetic factors contribute to its development, type, and severity.²,³

Various imaging modalities can be used to assess the extent, shape, thickness, and location of OPLL, including plain radiographs, magnetic resonance imaging (MRI), and computed...
tomography (CT) scans. The ossification is often classified
based on its morphology, distribution, or configuration of the
compressed spinal cord. Furthermore, OPLL can be categor-
ized according to its association with the vertebral bodies,
intervertebral discs, or the dura mater. The type of OPLL may
influence neurological symptoms, other imaging characteris-
tics, treatment strategies, outcomes, disease progression, and
risk of surgical complications.

While there are numerous classification systems in the lit-
erature, it is unclear how to best categorize various types of
OPLL. In addition, there is uncertainty as to what imaging
modality is the most reliable for diagnosing and classifying
OPLL. It is therefore the objective of this study to conduct a
literature review to

1. Summarize various classification systems used to
describe cervical OPLL
2. Evaluate the diagnostic accuracy of various imaging
modalities and the inter- and intrarater reliability of
classification systems.

**Methods**

**Eligibility Criteria**

Our review targeted studies on patients with cervical OPLL
with or without neurological signs and symptoms of myelopa-
thy. We sought studies that used a classification system to
categorize patients based on type of OPLL. Studies were
excluded if they stratified patients based on severity of stenosis
or occupying ratio (the thickest part of OPLL divided by the
anteroposterior diameter of the spinal canal).

**Information Sources**

Studies were identified using 4 electronic databases: MED-
LINE, MEDLINE in Process, EMBASE, and Cochrane Central
of Controlled Trials. The last search was run October 5, 2015.

**Search**

We used the following search terms to search all databases:
OPLL AND Cervical. Only studies on humans and written in
English or Japanese were considered for inclusion, with no
other limits applied.

**Study Selection**

All abstracts and titles were reviewed independently in an
unblinded, standardized manner by 2 of the authors (LT,
MK). The abstracts were sorted using predefined inclusion
criteria and classified as relevant, possibly relevant, or irrele-
vant. Any study that included patients with OPLL was further
investigated (LT, HN). Full text review of these articles was
done to determine whether a classification system was used to
define type of OPLL (all authors). Case reports were excluded
as well as case series that did not indicate or reference an OPLL
classification system. Systematic reviews, opinions, editorials,
and commentaries were also excluded.

**Data Extraction and Synthesis**

The following data was extracted from each included article:
patient sample and characteristics, the classification system
used to categorize OPLL, the image modality used to diagnose
OPLL, and any data on inter- and intrarater reliability.

**Reporting**

This systematic literature review was formatted based on the
Preferred Reporting Items for Systematic Reviews and Meta-
Analyses (PRISMA) statement.

**Results**

**Study Selection**

The search yielded a total of 1616 unique citations from Med-
line, Medline In-Process, EMBASE, and Cochrane Central
Register of Controlled Trials. After initial review of abstracts
and titles, 845 studies did not meet our inclusion criteria. Fol-
lowing full text investigation, an additional 405 studies were
excluded because (1) patients did not have OPLL, (2) a classi-
fication system was not used to categorize the type of OPLL,
and/or (3) they were systematic reviews or case reports.
Furthermore, 199 studies could not be located through the
libraries at the University Health Network, University of Tor-
onto, or University of Western Ontario mostly because they
were not in English. Seventy-five studies in Japanese were
obtained from the library at Nagoya University Graduate
School of Medicine; of these, 12 met our inclusion criteria.
In total, 167 studies were deemed relevant following this rig-
orous review process. Figure 1 provides an overview of our
search strategy.
Study Characteristics

For Objective 1, we identified 167 studies that used a classification system to categorize patients with OPLL. Sample sizes ranged from 5 to 581 patients. Diagnosis and classification of OPLL were based on findings from radiographs, CT scans, MRI, or a combination of modalities. Table 1 summarizes existing classification systems used for OPLL.

For Objective 2, we retrieved 9 studies that evaluated the inter- or intrarater reliability of classification systems and 7 that discussed correlations between and diagnostic accuracy of various imaging techniques. Table 2 reports the diagnostic accuracy of various imaging modalities and the reliability of several classification systems.

Part A: Classification Systems

Classifications Based on X-Ray

Nine-classification system (0.60% of articles). Nakanishi et al quantified the incidence of cervical OPLL in 698 asymptomatic subjects. This study classified the type of OPLL into 9 groups based on roentgenographic features: (1-3) isolated abnormal features at the upper, lower, or upper and lower edge of the posterior margin of the vertebrae; (4) abnormal features extending from the upper to lower posterior margin of a single vertebra; (5) “hornlike” abnormalities extending upwards; (6) “tail-like” abnormalities extending downwards; (7) board-like abnormalities extending upwards and downwards or areas of ossification fused with those of adjacent vertebrae; (8) areas of ossification extending from the lower vertebra to the posterior margin of upper cervical levels; and (9) ossification extending from the upper vertebra to the posterior margin of lower cervical levels.

Continuous, segmental, mixed, localized or focal, circumscribed, or other (92.81% of articles). The Investigation Committee for Ossification of the Spinal Ligaments (part of the Japanese Ministry of Health, Labour and Welfare) established a commonly used classification system for OPLL. This system categorizes OPLL into 4 types: (1) continuous, a long lesion extending over several vertebral bodies; (2) segmental, one or several separate lesions behind the vertebral bodies; (3) mixed, a combination of the continuous and segmental types; and (4) circumscribed, mainly located posterior to a disc space (Figure 2). In some studies, the term circumscribed was replaced by localized, solitary, or herniated/discal type (ie, ossification surrounding intervertebral disc herniation) and the term segmental by fragmented. In addition, a study by Sohn et al categorized OPLL into single or multilevel. Across 135 studies (n = 9150), 2381 (25.97%) patients were diagnosed with continuous, 3135 (34.26%) with segmental, 2971 (32.47%) with mixed, and 688 (7.30%) with either localized or circumscribed OPLL.

A study by Ito et al divided OPLL type into 6 groups: covered disc, covered vertebra, unconnected vertebra, connected vertebra (continuous), connected vertebra (localized), and other. The covered disc and covered vertebra groups were defined as ossification of the cranial or caudal vertebra with incomplete or complete coverage of the adjoining intervertebral disc, respectively. The unconnected vertebra group consisted of complete ossification of 2 adjacent vertebral bodies and the connecting intervertebral disc, with potential ossification of other cranial or caudal vertebrae or discs. The definitions for connected vertebra, either continuous or localized, were similar to those defined above. The other group had vertebrae with osteophytes, disc ossification, or no problematic features. In another study by Ito et al, OPLL morphology was classified as “connection department,” “coating part,” and “nonconnection department.” The “connection department” included both continuous and localized OPLL, whereas the “coating part” included either the tip of continuous or segmental OPLL.

Hook, staple, bridge, or total type (2.40% of articles). Three studies used a classification system proposed by Nakanishi et al: type I or hook, type II or staple, type III or bridge, and type IV or total/continuous. Hook-type OPLL appears as a single hook-shaped ossification localized to a part of the vertebral body, whereas staple type develops as a lesion extending the entire length of the vertebrae. Bridge type is similar to localized OPLL, with the ossification crossing from one vertebra to the other, whereas total type is analogous to continuous OPLL.

Classification based on the distribution and extent of OPLL (2.40% of articles). Two studies categorized patients with OPLL based on the distribution of OPLL. A study by Goto et al classified the type of OPLL as upper, lower, or wide. Upper type was defined as ossification involving the upper half of the cervical spine (C1-C3), lower type as ossification involving the lower half of the cervical spine (C4-C7), and wide type as ossification involving upper and lower levels of the cervical spine (C1-C7). In a study by Kawaguchi et al, patients were categorized into a C1(+) and C1(−) group; the C1(+) group had ossified lesions behind the dens at the level of the C1 lateral mass. Two other studies classified OPLL based on its extent.

K-line classification (4.19% of articles). Seven studies categorized patients into a (+) or (−) K-line group. The K-line was originally described by Fujiyoshi et al as a straight line connecting the midpoints of the spinal canal at C2 and C7 on a neutral lateral radiograph. A patient is classified as K-line (−) if the OPLL extends beyond the K-line and as K-line (+) if the OPLL does not (Figure 3).

Classifications Based on Computed Tomography

Free type, contiguous type, or broken sign (0.60% of articles). A single study classified OPLL plaques into 3 categories...
## Table 1. A Summary of Studies That Classified Type of OPLL.

| Classification System | Explanation | Studies |
|------------------------|-------------|---------|
| 9-Classification system | (1-3) Isolated abnormal features at the upper, lower, or upper and lower edge of the posterior margin of the vertebrae; (4) abnormal features extending from the upper to lower posterior margin of a single vertebra; (5) “hornlike” abnormalities extending upwards; (6) “tail-like” abnormalities extending downwards; (7) board-like abnormalities extending upwards and downwards or areas of ossification fused with those of adjacent vertebrae; (8) areas of ossification extending from the lower vertebra to the posterior margin of upper cervical levels; (9) ossification extending from the upper vertebra to the posterior margin of lower cervical levels. | Nakanishi (1973)⁴ |
| Continuous, segmental, mixed, localized or focal or circumscribed, and others | Continuous: a long lesion extending over several vertebral bodies<br>Segmental: one or several separate lesions behind the vertebral bodies<br>Mixed: a combination of the continuous and segmental types<br>Localized or focal or circumscribed: mainly located posterior to a disc space.<br>Refer to Figure 2 | Aita (1998),⁵ Baba (1995),⁶ Belanger (2005),⁷ Cao (2012),⁸ Chang (2010),⁹ Chang (2012),¹⁰ Chen (2009),¹¹ Chen (2013),¹² Chen (2009),¹³ Chen (2014),¹⁵ Chen (2014),¹⁶ Chiba (2005),¹⁷ Choi (2006),¹⁸ Chiba (2005),¹⁹ Chikuda (2011),²⁰ Choi (2014),²¹ Choi (2005),²² Epstein (1993),²³ Eun (2007),²⁴ Fujimori (2012),²⁵ Fujimori (2012),²⁶ Fujimori (2015),²⁸ Fujimori (2013),²⁹ Fujimori (2014),³⁷ Fujimori (1998),³⁰ Fujiya (1977),³¹ Fujiyoshi (2010),³² Goto (1995),³³ Gu (2014),³⁴ Hanakita (1994),³⁵ Harsh (1987),³⁶ Hasegawa (1997),³⁷ He (2013),³⁸ Hida (1997),³⁹ Hirabayashi (1981),⁴⁰ Hirai (1995),⁴¹ Hori (2006),⁴² Hori (2007),⁴³ Hossam (2013),⁴⁴ Isu (1997),⁴⁵ Isu (1994),⁴⁶ Ito (2015),⁴⁷ Ito (2013),⁴⁸ Ito (2015),⁴⁹ Iwasaki (2002),⁵⁰ Iwasaki (2007),⁵¹ Iwasaki (2009),⁵² Iwasaki (2009),⁵³ Izawa (1980),⁵⁴ Izumi (2013),⁵⁵ Jain (2005),⁵⁶ Jeon (2012),⁵⁷ Kadoya (2003),⁵⁸ Kalb (2011),⁵⁹ Kamikozuru (1991),⁶⁰ Kamizono (2003),⁶¹ Kang (2012),⁶² Kato (1998),⁶³ Kawabata (2009),⁶⁴ Kawaguchi (2008),⁶⁵ Kawaguchi (2001),⁶⁶ Kawaguchi (2014),⁶⁷ Kawaguchi (2014),⁶⁸ Kawaguchi (2011),⁶⁹ Kawaguchi (1991),⁷⁰ Kawano (1995),⁷¹ Kim (2007),⁷² Kim (2009),⁷³ Kim (2008),⁷⁴ Kim (2015),⁷⁵ Kimura (2012),⁷⁶ Kishiya (2009),⁷⁷ Kommu (2014),⁷⁸ Koyanagi (1998),⁷⁹ Koyanagi (2004),⁸⁰ Koyanagi (2003),⁸¹ Kudo (2011),⁸² Kudo (2013),⁸³ Kwon (2015),⁸⁵ Lai-qing (2015),⁸⁶ Lee (2013),⁸⁷ Lee (2015),⁸⁸ Lee (2015),⁸⁹ Lei (2014),⁹¹ Lei (2012),⁹² Li (2014),⁹³ Lin (2012),⁹⁴ Maruo (2014),⁹⁵ Matsunaga (2002),⁹⁶ Matsunaga (1999),⁹⁷ Matsunaga (1995),⁹⁸ Matsunaga (1994),⁹⁹ Matsunaga (2008),¹⁰⁰ Matsuoka (2001),¹⁰¹ Min (2007),¹⁰² Mizuno (2001),¹⁰³ Mizuno (2002),¹⁰⁴ Mizuno (2005),¹⁰⁵ Mizuno (2006),¹⁰⁶ Mochizuki (2009),¹⁰⁷ Morimoto (2000),¹⁰⁸ Morio (1999),¹⁰⁹ Morio (1993),¹¹⁰ Nakamura (1994),¹¹¹ Ogawa (2005),¹¹² Ogawa (2004),¹¹³ Ohtsuka (1987),¹¹⁴ Onari (2001),¹¹⁵ Onishi (2012),¹¹⁶ Ono (1977),¹¹⁷ Ono (1989),¹¹⁸ Otake (1992),¹¹⁹ Park (2008),¹²⁰ Sakai (2012),¹²¹ Sakou (1991),¹²² Sasaki (2014),¹²³ Sato (2007),¹²⁴ Sato (1977),¹²⁵ Seichi (2011),¹²⁶ Seichi (1992),¹²⁷ Sohn (2013),¹²⁸ Sohn (2014),¹²⁹ Son (2010),¹³⁰ Sugrue (2011),¹³¹ Sun (2011),¹³² Takami (2004),¹³³ Tateiwa (2003),¹³⁴ Tomitani (1980),¹³⁵ Tomita (1988),¹³⁶ Uchida (2005),¹³⁷ Wang (2008),¹³⁸ Wang (2008),¹³⁹ Wang (2011),¹⁴⁰ Wang (1999),¹⁴¹ Wang (2012),¹⁴² Wei (2014),¹⁴³ Wong (2011),¹⁴⁴ Yamashita (1988),¹⁴⁵ Yamashita (1990),¹⁴⁶ Yamauchi (1999),¹⁴⁷ Yang (2015),¹⁴⁸ Yang (2010),¹⁴⁹ Yang (1992),¹⁵⁰ Yang (2007),¹⁵¹ Yang (2015),¹⁵² Yasui (1983),¹⁵³ Yonenari (1997),¹⁵⁴ Yoshii (2014),¹⁵⁵ Yoshimura (2014),¹⁵⁶ Yuan (2015),¹⁵⁷ Yukawa (2015),¹⁵⁸ Zhao (2012),¹⁵⁹ (continued)
| Classification System                        | Explanation                                                                                                                                                                                                 | Studies                                                                                                                                 |
|---------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Bridging and nonbridging                    | **Bridging**: thick continuous ossification that connects intervertebral segments with bony union, or adjacent posterior margins of vertebral bodies at 2 or more levels **Nonbridging**: gaps within ossification or between the ossification and the vertebral bodies | Fujimori (2012),25 Kawaguchi (2014)67                                                                                                                                                          |
| Flat, Irregular, and localized              | **Flat**: long ossifications (with width >50% of spinal canal) located along the posterior margin of both the vertebral bodies and intervertebral discs at more than 3 continuous levels  
**Irregular**: irregular shaped ossifications (with width <50% of spinal canal) at more than 3 continuous vertebral levels, including those located only at the bilateral edge of the spinal canal and those with a double-edge shape  
**Localized**: ossifications spanning less than 3 continuous vertebral levels or located only behind the vertebral body | Kawaguchi (2011)19                                                                                                                                                                                |
| Dural ossification classification           | Categorized based on the association between the dura and the posterior longitudinal ligament Refer to Figure 7                                                                                           | Epstein (2001),169 Epstein (2009),170 Hida (1997),39 Min (2007),159 Mizuno (2005),104 Mizuno (2006),105 Yang (2015)147                  |
| Hook, staple, bridge, and total types       | **Hook**: single hook-shaped ossification localized to a part of the vertebral body  
**Staple**: ossification extending the entire length of the vertebrae  
**Bridge**: ossification crossing from one vertebra to the other; similar to localized OPLL  
**Total**: a long lesion extending over several vertebral bodies; similar to continuous OPLL                                                                 | Del Conte (1992),160 Jayakumar (1996),161 Nakanishi (1967),162 Nose (1987)163                                                                                                             |
| Free type, contiguous type, and broken sign | **Free**: ossification not in contact with the vertebral body in any plane  
**Contiguous**: ossification in contact with the vertebral body in at least one sagittal plane view  
**Broken**: a crack between 2 OPLL plaques in sagittal reformatted planes                                                                                                                                 | Chen (2011)166                                                                                                                                                                               |
| Hill, plateau, square, mushroom, irregular, or round shaped | **Plateau**: a relatively narrow spinal canal without any localized massive ossification  
**Hill**: a massive beak-shaped ossification localized to certain levels Refer to Figure 4                                                                 | Fujimori (2014),27 Ito (2015),47 Iwasaki (2007),51 Iwasaki (2009),53 Kim (2015),76 Ono (1989),117 Otake (1992),118 Son (2010),129 Yukawa (2015)157 |
| Triangular, teardrop, boomerang             | **Boomerang**: the spinal cord has a convex posterior surface and a concave anterior surface with a smooth round corner  
**Teardrop**: the spinal cord has a convex posterior surface and concave anterior surface with only a smooth round corner on one side  
**Triangular**: the spinal cord has an angular lateral surface and a flat anterior surface Refer to Figure 6                                                                 | Hossam (2013),44 Matsuyama (2004)168                                                                                               |
| Rectangular, oval, triangular, and pedunculate | Categorized based on shape of ossification on axial CT scan                                                                                                                                                 | Epstein (1993),23 Harsh (1987)26                                                                                                                                                              |
| Centralized or laterally deviated           | **Central**: posterior prominence of OPLL located in the middle third of the spinal canal  
**Lateral**: posterior prominence of OPLL not located in the middle third of the spinal canal; divided into left and right subtypes                                                                 | Kawaguchi (2014),47 Matsunaga (2008),100 Onishi (2012)115                                                                                                                                     |
| Plank, spindle, or rod shaped               | **Plank**: thick ossification that protrudes posteriorly at disc spaces  
**Spindle**: ossification tapered and rounded at the upper and lower borders                                                                                                                                 | Terada (1997)167                                                                                                                                                                               |
| Classification based on the distribution of OPLL | Categorized based on location of OPLL                                                                                                                                                                       | Cao (2012),8 Goto (1995),33 Kawaguchi (2008),65 Morimoto (2000)107 Fujimori (2014),27 Fujiyoshi (2008),164 Ito (2015),47 Kwon (2015),85 Maruo (2014),94 Nagashima (2013),165 Yukawa (2015)157 |
| K-line classification                        | The K-line is a straight line connecting the midpoints of the spinal canal at C2 and C7 on a neutral lateral radiograph. A patient is classified as K-line (−) if the OPLL extends beyond the K-line and as K-line (+) if the OPLL does not Refer to Figure 3 | Refer to Figure 3                                                                                                                                                                               |
| Rule of nine                                 | N/A                                                                                                                                                                                                        | Yang (2015)147                                                                                                                          |

Abbreviations: OPLL, ossification of the posterior longitudinal ligament; CT, computed tomography.
surgically resected completely and safely. A free-type plaque was defined as ossification not in contact with the vertebral body in any plane. On the other hand, a contiguous plaque is in contact with the vertebral body in at least one sagittal plane view. A broken sign was defined as a crack between 2 OPLL plaques in the sagittal reformatted planes.

Hill, plateau, square, mushroom, irregular, or round shaped (5.99% of articles). Ten studies used hill, plateau, mushroom, irregular, or round shaped to classify the type of OPLL (Figure 4). Plateau-shaped ossification is characterized by a relatively narrow spinal canal without any localized massive ossification. In contrast, hill-shaped OPLL appears as a massive beak-shaped ossification localized to certain levels. Plateau-shaped ossification is often found in segmental- and in most cases of continuous- and mixed-type OPLL, whereas hill-shaped OPLL is typically associated with circumscribed ossification. In a study by Otake et al, OPLL was classified into 3 types based on its shape on axial MR images: (1) square with parallel lines tangential to the bilateral margins of the ossified lesion, (2) mushroom with ventrally crossing lines, and (3) hill with dorsally crossing lines. Mushroom shaped was also used to define the type of OPLL in a study by Son et al. Finally, Ono et al used mushroom, irregular, and round to categorize the shape of ossification.

Rectangular, oval, triangular, or pedunculate (1.20% of articles). Two studies classified OPLL based on the shape of the mass on an axial CT scan: rectangular, oval, triangular, or pedunculated. No further explanation was provided of these categories.

Centralized or laterally deviated (1.80% of articles). Three studies classified the type of OPLL as central or laterally deviated based on its position on an axial CT scan. OPLL was categorized as central if the posterior prominence of the OPLL was located in the middle third of the spinal canal. The lateral-type OPLL was further divided into left and right subtypes.

Plank, spindle, or rod shaped (0.60% of articles). A single study used 3-dimensional CT image reconstruction to visualize the configurations of OPLL in the cervical spine. The OPLL was classified as plank, spindle, or rod shaped. In plank-shaped OPLL, the region of ossification is thick and protrudes posteriorly at disc spaces. Furthermore, the ossified ligament typically abuts the vertebral bodies; however, in some cases, there may be a gap between the OPLL and the posterior margins of the vertebral bodies. Spindle-shaped OPLL is tapered and rounded at the upper and lower borders. Finally, patients with rod-shaped OPLL have relatively thin, short rods of ossification typically confined to the center of the posterior margin of the vertebral body and discontinued at the intervertebral discs.

Rule of nine (0.60% of articles). A new method of classifying OPLL was developed to determine whether the ligament can be surgically resected completely and safely. On axial CT scans, 2 points were marked at the junction of the vertebral body and pedicle and a straight “baseline” was drawn between the points. The space between the posterior margin of the vertebral body and the root of the spinous process was divided into 3 equal parts by 2 lines, the safety and danger lines. The space (1) between the baseline and safety lines was the safety zone, (2) between the safety and danger lines was the intermediate zone, and (3) below the danger line was the danger zone. The baseline was also divided into 3 equal parts by 2 perpendicular lines, creating a 9-square grid.

Classifications Based on 3-Dimensional Computed Tomography

Bridging or nonbridging (1.20% of articles). In 2 studies, OPLL was classified as bridging or nonbridging using 3-dimensional CT scans. Bridging OPLL was defined as a thick continuous ossification that connected (1) intervertebral segments with bony union or (2) adjacent posterior margins of vertebral bodies at 2 or more levels. In contrast, patients with nonbridging OPLL had gaps within the ossification or between the ossification and vertebral bodies. A third type of OPLL, stalagmite type, was identified in patients with nonbridging OPLL due to differences in range of motion. In this type of OPLL, the ossification originates from the lower vertebra and progresses continuously through and behind the upper vertebral body without contact, imitating stalagmite geological formations.

Kawaguchi et al used another classification system to describe all vertebral and intervertebral levels where OPLL was greater than 2 mm in width: (1) a dot (“.”) is placed when the OPLL is disconnected, (2) a slash (“/”) is used when the OPLL lesion is beyond the intervertebral level without any bridge formation to the adjacent vertebral body, (3) a bar (“-”) is drawn when the ossification is beyond the intervertebral level with bridge formation to the adjacent vertebral body, and (4) the vertebra is circled when the OPLL lesion is not attached to it.

Flat, irregular, or localized (0.60% of articles). Using 3-dimensional CT, OPLL can be classified into 3 types: flat, irregular, and localized (Figure 5). In flat OPLL, long ossifications are located along the posterior margin of both the vertebral bodies and intervertebral discs at more than 3 continuous levels. The width of ossification is more than 50% of the spinal canal. The irregular type of OPLL consists of irregular-shaped ossifications at more than 3 continuous vertebral levels, including those located only at the bilateral edge of the spinal canal and those with a double-edge shape. The width of the ossification is less than 50% of the spinal canal. Finally, in the localized type, ossifications span less than 3 continuous vertebral levels or are located only behind the vertebral body.

Classification Based on Magnetic Resonance Imaging

Triangular, teardrop, or boomerang (1.20% of articles). Two studies classified OPLL into 3 types based on the configuration of the compressed spinal cord on T2-weighted axial images: boomerang, teardrop, and triangular (Figure 6). In the boomerang type, the spinal cord has a convex posterior surface...
Table 2. Reliability of Imaging Modalities for Diagnosis and Classification of OPLL.

| Diagnosis of OPLL | Interobserver Reliability | Intraobserver Reliability | Diagnostic Accuracy |
|-------------------|---------------------------|---------------------------|---------------------|
|                    | **Kudo et al (2013)**²⁷⁴ | **Kudo et al (2013)**²⁷⁴ | **Wong et al (2011)**²⁴³ |
| Radiographs:       | \( \kappa = 0.878 \) (residents), \( \kappa = 0.817 \) (specialists), \( \kappa = 0.787 \) (total) | Radiographs: \( \kappa = 0.537 \) (residents), \( \kappa = 0.690 \) (specialists), \( \kappa = 0.613 \) (total) | MRI: true positives = 20/45 cases; false negatives = 21/45 cases; false positives = 4/45 cases |
| Radiographs + CT images: | \( \kappa = 0.823 \) (residents), \( \kappa = 0.832 \) (specialists), \( \kappa = 0.853 \) (total) | Radiographs + CT images: \( \kappa = 0.795 \) (residents), \( \kappa = 0.808 \) (specialists), \( \kappa = 0.802 \) (total) | Mizojo et al (2005)²⁰⁴ |
| CT images:         | \( \kappa = 0.70 \) |                      | CT images: 100% |
| Sohn et al (2014)²⁸ | CT images: \( \kappa = 0.896 \) |                      | Lateral radiographs: 88.24% |
|                   | CT images: \( \text{72.4} \% \pm \text{8.8}\% \) (95% CI: 67.5% to 76.8%) |                      | Polytomography: 70.59% |
|                   | Jeon et al (2012)²⁵⁷ |                      | MRI: 76.47% |
| Radiographs + CT images: | \( \kappa = 0.81 \) |                      | Kang et al (2012)²⁶² |
|                   |                       |                      | MRI 52.2%; false negatives = 41.3% |
|                   |                       |                      | Lateral radiographs: 58.7%; false negatives = 47.8% |
|                   |                       |                      | Otake et al (1992)²¹⁸ |
|                   |                       |                      | Sagittal T1-WI: 32.7% |
|                   |                       |                      | Sagittal proton density: 70.2% |
|                   |                       |                      | Sagittal T1-WI: 44.3% |
|                   |                       |                      | Axial T1-WI: 74.1% |
|                   |                       |                      | Axial proton density: 97.8% |
|                   |                       |                      | T2-WI: 91.1% |
|                   |                       |                      | Jeon et al (2012)²⁵⁷ |
| Classification of OPLL | **Chang et al (2009)**³⁹ | **Chang et al (2009)**³⁹ | **Izumi et al (2013)**³⁵⁵ |
| Classification System Proposed by the Japanese Ministry of Health, Labour and Welfare | Lateral radiograph + axial CT: 77% (\( \kappa = 0.67 \)) | Lateral radiograph + axial CT: 77% (\( \kappa = 0.67 \)) | 60% concordance between CT and X-rays |
| Chang et al (2010)⁹ | 2-Dimensional CT: 85% (\( \kappa = 0.76 \)) | 2-Dimensional CT: 85% (\( \kappa = 0.76 \)) | |
|                   | 3-Dimensional CT: 85% (\( \kappa = 0.76 \)) | 3-Dimensional CT: 85% (\( \kappa = 0.76 \)) | |
|                   | Kudo et al (2013)²⁷⁴ | Kudo et al (2013)²⁷⁴ | |
|                   | Radiographs: \( \kappa = 0.526 \) (residents), \( \kappa = 0.630 \) (specialists), \( \kappa = 0.574 \) (total) | Radiographs: \( \kappa = 0.392 \) (residents), \( \kappa = 0.561 \) (specialists), \( \kappa = 0.477 \) (total) | |
|                   | Radiographs + CT images: \( \kappa = 0.622 \) (residents), \( \kappa = 0.733 \) (specialists), \( \kappa = 0.658 \) (total) | Radiographs + CT images: \( \kappa = 0.544 \) (residents), \( \kappa = 0.665 \) (specialists), \( \kappa = 0.605 \) (total) | |
| Segmental          | **Chang et al (2010)**⁹ | **Chang et al (2010)**⁹ | Kang et al (2012)²⁶² |
|                   | Lateral radiograph + axial CT: 77% | Lateral radiograph + axial CT: 85% | Plain X-ray: 27.3% |
| Chang et al (2010)⁹ | 2-Dimensional CT: 87% | 2-Dimensional CT: 96% | MRI: 31.8% |
|                   | 3-Dimensional CT: 89% | 3-Dimensional CT: 97% | Plain radiographs: 25.34% |
|                   |                       |                       | 2-Dimensional CT: 35.62% |
|                   |                       |                       | Otake et al (1992)²¹⁸ |
|                   |                       |                       | Frequency of visualized increased intensity on sagittal T1-weighted MRI: 3.4% |
| Continuous         | **Chang et al (2010)**⁹ | **Chang et al (2010)**⁹ | Kang et al (2012)²⁶² |
|                   | Lateral radiograph + axial CT: 17% | Lateral radiograph + axial CT: 50% | Plain X-ray: 85.7% |
| Chang et al (2010)⁹ | 2-Dimensional CT: 62% | 2-Dimensional CT: 79% | MRI: 100% |
|                   | 3-Dimensional CT: 73% | 3-Dimensional CT: 84% | Plain radiographs: 15.75% |
|                   |                       |                       | 2-Dimensional CT: 11.64% |
|                   |                       |                       | Otake et al (1992)²¹⁸ |
|                   |                       |                       | Frequency of visualized increased intensity on sagittal T1-weighted MRI: 80.6% |

(continued)
and a concave anterior surface with a smooth round corner. The teardrop type has a convex posterior surface and concave anterior surface with only a smooth round corner on one side, and the triangular type has an angular lateral surface and a flat anterior surface.

Classifications Based on Association With the Dura Mater

Dural ossification (4.19% of articles). Seven studies classified OPLL based on its association with the dura mater (Figure 7).39,104,105,148,159,169,170 There are several implications to correctly identifying patterns of dural ossification, including reducing the risk of cerebrospinal fluid leakage after anterior decompression. In the original study, Hida et al defined a single-layer sign as a large focal mass of uniformly hyperdense OPLL and a double-layer sign as a central hypodense line of hypertrophied ligament between an anterior rim and a posterior rim of hyperdense ossification (ie, OPLL involving the posterior aspect of the vertebral body and intradural ossification).39

In 2 studies by Mizuno et al, dural ossification was further classified into 3 types based on its shape and association with the OPLL: (1) an isolated type where the dural ossification is not related to the OPLL, (2) a double-layer type where the dural ossification and OPLL are separated by an epidural space, and (3) an en
bloc type where there is en bloc ossification of the dura mater and OPLL, with a meningeal tail sign on a sagittal slice.\textsuperscript{104,105}

The double-layer sign was further characterized into types A, B, and C based on morphological features of the ossified and central hypodense mass.\textsuperscript{148} In type A, the hypodense mass is crescent shaped and the OPLL is much more extensive than the dural ossification. Type B is a short straight hypodense line less than or equal to half of the base width of the vertebrae. Finally, in type C, the dural ossification is much more extensive than the OPLL, and the central hypodense mass is a long straight line that extends more than half of the base width of the vertebrae.

Finally, Epstein et al characterized 2 signs of dural penetration: the modified single-layer sign and the double-layer sign.\textsuperscript{169} The modified single-layer sign was characterized by a laterally curved and irregular mass of OPLL with a unique hook-like configuration. A third sign, the smooth-layer sign, indicated an intact dura and was defined as a more classic OPLL without a hook-like C sign.

**Part B: Inter- and Intrarater Reliability**

Reliability is generally assessed by computing either correlations between continuous variables or $\kappa$ values for categorical variables. Criteria for strength of agreement are as follows: a $\kappa$ of 0.81 to 1.00 as almost perfect, 0.61 to 0.80 as substantial, 0.41 to 0.60 as moderate, 0.21 to 0.40 as fair, and 0.00 to 0.20 as slight agreement.\textsuperscript{171}

Reliability of OPLL Diagnosis Using Various Imaging Modalities. The reliability of OPLL diagnosis was reported by 5 studies.\textsuperscript{28,57,67,84,128} In a study by Kudo et al, 8 spine surgery specialists and 8 orthopedic residents were instructed to diagnose either OPLL or cervical spondylotic myelopathy using radiographs only and then both radiographs and CT images.\textsuperscript{84} To test intraobserver reliability, the same individuals were asked to reanalyze the images at least 24 hours after the first evaluation. In the second round, the interobserver reliability was $\kappa = 0.787$ with radiographs only ($\kappa = 0.817$ among specialists, $\kappa = 0.878$ among residents) and $\kappa = 0.853$ using both radiographs and CT images ($\kappa = 0.832$ among specialists and $\kappa = 0.823$ among residents). These values were higher than interobserver reliabilities after first round of analysis. Intraobserver reliability of diagnosis was $\kappa = 0.613$ ($\kappa = 0.690$ among specialists, $\kappa = 0.537$ among residents) using only radiographs and was $\kappa = 0.802$ ($\kappa = 0.795$ among specialists, $\kappa = 0.808$ among residents) using both radiographs and CT images. In 3 other
studies, diagnosis agreement using CT scans was $\kappa = 0.70$ to 0.896 between a radiologist(s) and an experienced orthopedic spine surgeon.\textsuperscript{28, 67, 128}

Wong et al analyzed the agreement between MRI and CT scans for OPLL diagnosis.\textsuperscript{143} Forty-five patients were first evaluated by MRI and then assessed by follow-up CT scans to confirm the presence or absence of OPLL. Of the 45 cases, 20 were correctly diagnosed using MRI (true positive), whereas in 21 cases, OPLL was not identified (false negative; sensitivity

**Figure 4.** Classification of ossification morphology: hill, plateau, and mushroom shaped.

The radiographs in the top panel display (from left to right) plateau-shaped OPLL, hill-shaped ossification in a beak configuration, and hill-shaped circumscribed type of OPLL. The bottom panel illustrates 3 types of OPLL morphology: (from left to right) square, mushroom, and hill shape. Derived from Otake et al (1992) and Iwasaki et al (2007).

**Figure 5.** Novel classification system proposed by Kawaguchi et al (2011) using 3-dimensional computed tomography. From left to right: flat, irregular, and localized type of OPLL. Derived from Kawaguchi et al (2011).

**Figure 6.** Classification of OPLL based on the configuration of the compressed spinal cord: triangular, teardrop, and boomerang. From top to bottom: boomerang, teardrop, and triangular configurations of the compressed spinal cord on axial magnetic resonance imaging. Derived from Matsuyama et al (2004).

**Figure 7.** Types of dural ossification. The top 3 panels illustrate (from top to bottom) isolated, double-layer, and en bloc types of dural ossification. The bottom panel depicts the types of the double-layer sign: (from left to right) type A or crescent shape, type B or short-straight shape, and type C or long-straight shape. Derived from Mizuno et al (2005) and Yang et al (2015).
of 49%). Furthermore, 4 patients were diagnosed as having OPLL on MRI when it was not detected on CT imaging (false positive; positive predictive value of 83%). Mizuno et al compared the ability of various neuroimaging modalities to diagnose OPLL in 17 patients, including lateral plain radiography, thin slice sagittal polytomography, CT scans, and T2-weighted MRI. The best modalities were bone window CT scanning and lateral plain radiography, which correctly identified 100.00% and 88.24% OPLL cases, respectively. Polytomography detected OPLL in 12 of 17 patients (70.59%) and MRI in 13 of 17 cases (76.47%). Interestingly, the 4 cases that were incorrectly diagnosed by MRI were segmental OPLL as the ossification could not be differentiated from the posterior spur or the degenerated hypertrophied posterior longitudinal ligament.

A single study compared the diagnostic accuracy of CT scans versus MRI and plain lateral radiographs. MRI and plain lateral radiographs were only able to detect OPLL in 52.2% and 58.7% of cases, respectively. The false negative rate on MRI was 41.3% and on plain lateral radiographs was 47.8%. On MRI, the main misdiagnosis was hypertrophied posterior longitudinal ligament, whereas on plain lateral radiographs, any OPLL less than 2.99 mm thickness was not detected.

Finally, a study by Otake et al reported the likelihood of detecting ossified lesions of variable thickness on T1-weighted, proton density, and T2-weighted MRI. In the sagittal plane, OPLL was more frequently identified on proton density imaging (70.2%) than on T1- (32.7%) and T2-weighted (44.3%) images. On T1- and T2-weighted images, ossification may be mistaken for cerebrospinal fluid or vertebral bodies, respectively. The chance of detecting ossification increased with the thickness of the lesion. OPLL was better detected on axial imaging: (1) 74.1% on T1-weighted MRI, (2) 97.8% on proton density imaging, and (3) 91.1% on T2-weighted imaging. Increased intensity within the ossified lesion was visualized in 61 of 147 patients on T1-weighted imaging and more commonly seen in patients with thick ossification.

The Reliability of the Classification System Proposed by the Japanese Ministry of Health, Labour and Welfare. Two studies evaluated the reliability of the classification system proposed by the Japanese Ministry of Health, Labor and Welfare. In a study by Chang et al, 5 spine surgeons were required to classify the type of OPLL in 108 patients using lateral radiographs, axial CT scans, and 2- and 3-dimensional reconstructed CT images. The interobserver reliability of the classification system ranged from $\kappa = 0.51$ on lateral radiographs and axial CT scans to $\kappa = 0.76$ on 3-dimensional CT. As reported by Kudo et al, the interobserver reliability was $\kappa = 0.574$ using just radiographs and $\kappa = 0.658$ using both radiographs and CT images. Finally, in a study by Izumi et al, the classification using X-rays corresponded with that of CT images in 9 out of 15 cases (60.0%).

All types of OPLL were better classified using only 2-dimensional (continuous: 62%, segmental: 87%, mixed: 83%, circumscribed: 92%) and 3-dimensional reconstructed CT images (continuous: 73%, segmental: 89%, mixed: 86%, circumscribed: 92%) than using lateral radiographs in combination with axial CT images (continuous: 17%, segmental 77%, mixed: 74%, circumscribed: 88%). The diagnostic accuracy of lateral radiographs and MRI was further explored by Kang et al. Plain X-rays were able to better classify continuous (85.7%) and mixed (91.7%) OPLL compared to segmental (27.3%) and localized (20.0%) types. Diagnostic accuracy on MRI was slightly different: 100% in continuous, 31.8% in segmental, 83.3% in mixed, and 60.0% in localized OPLL. The percentage of false negatives was higher in segmental (68.2% on MRI and 72.7% on lateral radiographs) and localized (40.0% on MRI and 80.0% on lateral radiographs) OPLL than in the continuous (0.0% on MRI and 14.3% on lateral radiographs) and mixed (16.7% on MRI and 8.3% on lateral radiographs) types. Increased signal intensity on T1-weighted images within the ossified ligament was more frequently seen in patients with continuous (80.6%) and mixed (60.7%) lesions than in those with segmental (3.4%) and circumscribed (0.0%) OPLL.

Intraobserver reliability of the classification system was $\kappa = 0.477$ using radiographs, $\kappa = 0.605$ to 0.67 using a combination of radiographs and CT scans, $\kappa = 0.85$ using 2-dimensional CT, and $\kappa = 0.86$ using 3-dimensional CT scans. The intraobserver reliability was high for segmental, mixed, and circumscribed OPLL using lateral radiographs and axial CT (85%, 82%, and 91%, respectively), 2-dimensional CT (96%, 94%, and 99%), and 3-dimensional (97%, 94%, and 97%) CT.

Detection of continuous OPLL, however, had low intraobserver reliability using lateral radiographs and axial CT (50%), but good reliability using 2- (79%) and 3-dimensional (84%) CT.

Reliability of Identifying Dural Ossification. A single study calculated the reliability of correctly identifying dural ossification, whereas 2 studies reported the diagnostic accuracy of various imaging modalities. Yang et al reported a kappa value of $\kappa = 0.82$ for classifying the 3 types of dural ossification. A second study explored the ability of various neuroimaging modalities to detect OPLL and dural ossification in 17 patients, including lateral plain radiography, thin slice sagittal polytomography, CT scans, and T2-weighted MRI. The results were (1) bone-window CT scanning was able to detect dural ossification in all 17 cases of OPLL, (2) polytomography could only identify dural ossification in 7 out of 12 cases (58.3%), (3) only 4 of 15 cases of dural ossification were detected on lateral plain radiographs, and (4) MRI could not distinguish dural ossification in any of the 13 OPLL patients. A third study evaluated the value of the double-layer sign for the diagnosis of dural ossification. On axial CT images, the sensitivity of this method was 55% and the specificity was 96.9%. The sensitivity was much higher in patients with mild OPLL (occupying ratio <60%, sensitivity = 81%) and lower in patients with severe OPLL (occupying ratio ≥60%, sensitivity = 26%).

Reliability of Other Classification Systems. The reliability of 4 other classification systems was evaluated. The interobserver
reliability of classifying the type of attachment as free or contiguous was \( \kappa = 0.849 \) between a radiologist and experienced spine surgeon, indicating high reliability of this method.\(^{166}\)

The interobserver reliability among 7 senior spine surgeons was \( \kappa = 0.43 \pm 0.26 \) for the bridging and nonbridging types of OPLL proposed by Kawaguchi et al.\(^{67}\)

The mean inter- and intraobserver reliabilities of the “rule of nine” classification system were \( \kappa = 0.76 \) and \( \kappa = 0.84 \), respectively.\(^{147}\)

Using 3-dimensional CT images, the inter- and intraobserver reliabilities were \( \kappa = 0.78 \) and \( \kappa = 0.86 \), respectively, for classifying patients with flat, irregular, or localized OPLL.\(^{69}\)

**Discussion**

This study summarizes various classification systems used to categorize patterns of cervical OPLL. Our results indicate that OPLL can differ substantially with respect to its shape, extent, and distribution and the configuration of the compressed spinal cord. Furthermore, the ossification can be associated with the dura mater and different components of the spinal column. Appropriate classification of OPLL is critical as there may be significant variations in neurological presentation, surgical outcomes, disease progression, and risk of complications across subtypes of OPLL. Based on our review, the most common method of classification was that proposed by the Japanese Ministry of Health, Labor and Welfare (continuous, segmental, mixed, localized, or circumscribed). Other important means of categorizing OPLL include using the K-line (\( \pm \)), identifying signs of dural ossification, and by distribution. In terms of reliability and accuracy, our results indicate that OPLL is best diagnosed and classified using 2- or 3-dimensional CT images.\(^9\) In addition, the reliability is high for Yang’s classification of dural ossification and Chen’s free or contiguous method.\(^{148,166}\)

Patients with different types of OPLL may have different risks of developing myelopathy or of experiencing a traumatic spinal cord injury. In a study by Matsunaga et al, laterally deviated OPLL on an axial MRI or CT scan was an important predictor of myelopathy development (\( P = .021 \)).\(^{100}\) Chang et al evaluated differences in type of OPLL (continuous, mixed, segmental, or localized) between patients with no symptoms, neck pain, or radiculopathy and those with myelopathy.\(^6\) In the myelopathy group, 15% of subjects had localized ossification, 35% segmental, 24% continuous, and 26% mixed OPLL. This is in contrast to the asymptomatic, neck pain, or radiculopathy group: 8% localized type, 60% segmental, 8% continuous, and 24% mixed. In a third study, however, the type of OPLL (segmental, continuous, or mixed) was not predictive of progressive myelopathy. The risk of trauma-induced myelopathy was significantly higher in patients with mixed-type OPLL than in those with segmental or continuous type.\(^{96}\) However, this finding could not be replicated in a study by Onishi et al, which reported no risk difference among patients with segmental, continuous, mixed, or localized OPLL.\(^{115}\) The ratio of central to laterally deviated ossification was also similar between a spinal cord injury group and a cervical myelopathy (control) group.\(^{115}\)

Different subtypes of OPLL may also vary in terms of neurological symptoms, preoperative myelopathy severity, occupying ratio, space available for the spinal cord, range of motion, and segmental stability. A single study compared symptoms among OPLL subtypes (continuous, segmental, or mixed) using the visual analog scale (VAS) and Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ).\(^{122}\) Based on their results, neck function on the JOACMEQ in patients with continuous OPLL was significantly lower than those with mixed-type ossification. However, there were no significant differences in upper and lower extremity function, urinary function, quality of life, shoulder stiffness, and neck/arm pain among subtypes. Furthermore, preoperative JOA was similar between patients with mixed, segmental, continuous, and localized OPLL.\(^{44,154}\) Interestingly, patients with bridging OPLL were more stable over a 2 year monitoring period than those with nonbridging ossification.\(^{26}\)

Mixed and continuous types of OPLL are associated with a greater percentage of spinal canal stenosis, a smaller space available for the spinal cord, an increased compression ratio, and a higher occupying ratio compared to patients with segmental or localized ossification.\(^{30,59,115,139}\) Furthermore, patients with mixed or continuous OPLL have a greater dynamic OPLL distance than those with segmental ossification. In contrast, a single study reported no difference in the space available for the spinal cord or occupying ratio in patients with mixed, segmental, or continuous OPLL.\(^{32}\) In addition, Koyanagi et al concluded that patients with segmental OPLL have significantly narrower diameters at C3-C7 than patients with continuous or mixed ossification.\(^{82}\) K-line (\( \pm \)) OPLL is associated with decreased C2-C7 range of motion and increased occupying ratio, extension/flexion ratio, and thickness.\(^{47,164,165}\) Moreover, a greater percentage of patients with K-line (\( \pm \)) OPLL are compressed at flexion, whereas those with K-line (\( \pm \)) are more likely to be compressed at extension.\(^{47}\)

Range of motion also varies across subtypes of OPLL. In a study by Fujimura et al, patients with continuous ossification had reduced range of motion as compared to those with mixed, segmental, or localized OPLL.\(^{30}\) Bridging OPLL is also associated with smaller intervertebral range of motion in both anteroposterior flexion and axial rotation compared to nonbridging OPLL.\(^{26}\) Furthermore, those with staghorn nonbridging ossification had significant smaller anteroposterior flexion than other nonbridging types. Yoshii et al concluded that these mobile segments without complete bridging were the areas of greatest spinal cord compression.\(^{154}\)

Patients with different types of OPLL may also vary with respect to surgical outcomes, progression rates, and risk of complications. Several studies have evaluated surgical outcomes in patients with different types of OPLL. For example, patients with K-line (\( \pm \)) OPLL may have significantly higher recovery rates and postoperative JOA scores than patients with...
K-line (—) OPLL. Hill-shaped OPLL (vs plateau-shaped) was also predictive of worse recovery rates following surgery in a single study. Finally, according to Matsuyama et al, patients with triangle-shaped cord compression have significantly lower postoperative JOA scores and reduced recovery than those with boomerang- or tear-shaped compression. In contrast, type of OPLL (continuous, mixed, segmental, or localized) and presence of dural ossification were not associated with surgical outcomes.

Further investigation is required to determine important OPLL predictors of outcome in patients undergoing surgery for OPLL-related myelopathy.

Progression of OPLL was defined as (1) an increase in the longitudinal extent of the ossification by 2 mm or more, (2) an increase in the thickness or sagittal extent of the ossification by 2 mm or more, (3) appearance of a new lesion, and/or (4) the bridging of 2 or more existing lesions to form a continuous segment. This progression can significantly reduce the space available for the spinal cord, cause neurological deterioration, and result in new debilitating signs and symptoms. It is therefore essential to identify patients at high risk of progression, implement appropriate preventative surgical strategies, and regularly monitor these patients following surgery. Five studies evaluated important predictors of OPLL progression and reported that patients with mixed or continuous OPLL were at a higher risk of progression than those with segmental ossification.

Finally, certain types of OPLL may be predictive of surgical complications. In particular, patients with dural ossification are at a higher risk of cerebrospinal fluid leakage following anterior cervical surgery as it is technically difficult to separate the posterior longitudinal ligament from an ossified dura. Clinicians must identify these high-risk patients and implement rigorous preventative strategies to avoid cerebrospinal fluid leakage and damage to the spinal cord and nerve roots (ie, anterior floating method or separation of ligament from dural ossification through a thin layer of nonossified ligament). Furthermore, surgeons must appropriately educate their patients and be prepared to manage leaks either through direct dural repair, lumbar drains, or chemical seals. Based on 3 studies, patients with a double-layer sign are more likely to have a dural defect than patients with a single-layer sign. In contrast, there is no difference in the rate of dural penetration between patients with a single-layer sign versus those with no sign. Using the classification system developed by Yang et al, patients with type C dural ossification are at a much higher risk of cerebrospinal fluid leakage than patients with type A or B, and those with type B are at a higher risk than patients with type A. Finally, Epstein et al demonstrated a moderate correlation between her modified single-layer with C sign and dural penetration.

While these categorizations are important to distinguish between potential pathological differences, they are based on conceptual and theoretical factors. In practice, it is not always a simple endeavor to categorize OPLL into a specific group. These classifications would be much more useful if they were further supported by other imaging factors, clinical findings, and neurological features.

Conclusions and Knowledge Gaps

This study has identified substantial heterogeneity in the methodology used to diagnose and classify OPLL. Based on this review, OPLL is best diagnosed using 2- or 3-dimensional CT imaging. Several published studies, however, have not used these modalities to identify ossification; as a result, OPLL may be either underdiagnosed or mistaken for milder forms of degenerative calcification. The lack of a standardized and reliable classification system prevents clinicians and researchers from addressing key questions surrounding the natural history, evaluation, and management of OPLL and outcomes related to various interventions. Future studies should use this review as a basis for developing a more reliable classification system for OPLL; given the heterogeneity in presentation, the term “OPLL-spectrum disorder” may be valuable.

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References

1. Matsunaga S, Sakou T. Ossification of the posterior longitudinal ligament of the cervical spine: etiology and natural history. Spine (Phila Pa 1976). 2012;37:E309-E314.
2. Stapleton CJ, Pham MH, Attinello FJ, Hsieh PC. Ossification of the posterior longitudinal ligament: genetics and pathophysiology. Neurosurg Focus. 2011;30(3):E6.
3. Nouri A, Tetreault L, Singh A, Karadimas SK, Fehlings MG. Degenerative cervical myelopathy: epidemiology, genetics, and pathogenesis. Spine (Phila Pa 1976). 2015;40:E675-E693.
4. Nakajishi T, Mannen T, Toyokura Y. Asymptomatic ossification of the posterior longitudinal ligament of the cervical spine. Incidence and roentgenographic findings. J Neurol Sci. 1973;19:375-381.
5. Aita I, Ohno A, Amagai H, Hirabayashi H, Hayashi K. Histomorphic study of iliac bones in cervical myelopathy with ossification of the posterior longitudinal ligament. J Orthop Sci. 1998;3:324-329.
6. Baba H, Furusawa N, Chen Q, Imura S. Cervical laminoplasty in patients with ossification of the posterior longitudinal ligaments. Paraplegia. 1995;33:25-29.
7. Belanger TA, Roh JS, Hanks SE, Kang JD, Emery SE, Bohman HH. Ossification of the posterior longitudinal ligament. Results of anterior cervical decompression and arthrodesis in sixty-one North American patients. J Bone Joint Surg Am. 2005;87:610-615.
8. Cao JM, Zhang YZ, Shen Y, et al. Selection of operative approaches for multilevel cervical spondylotic myelopathy by imageological score. J Spinal Disord Tech. 2012;25:99-106.
9. Chang H, Kong CG, Won HY, Kim JH, Park JB. Inter- and intra-observer variability of a cervical OPLL classification using reconstructed CT images. *Clin Orthop Surg*. 2010;2:8-12.

10. Chang H, Song KJ, Kim HY, Choi BW. Factors related to the development of myelopathy in patients with cervical ossification of the posterior longitudinal ligament. *J Bone Joint Surg Br*. 2012;94:946-949.

11. Chen Y, Chen D, Wang X, et al. Anterior corpectomy and fusion for severe ossification of posterior longitudinal ligament in the cervical spine. *Int Orthop*. 2009;33:477-482.

12. Chen Y, Chen D, Wang X, et al. Significance of segmental instability in cervical ossification of the posterior longitudinal ligament and treated by a posterior hybrid technique. *Arch Orthop Trauma Surg*. 2013;133:171-177.

13. Chen Y, Guo Y, Chen D, et al. Diagnosis and surgery of ossification of the posterior longitudinal ligament associated with dural ossification in the cervical spine. *Eur Spine J*. 2009;18:1541-1547.

14. Chen Y, Guo Y, Chen D, Wang X, Lu X, Yuan W. Long-term outcome of laminectomy and instrumented fusion for cervical ossification of the posterior longitudinal ligament. *Int Orthop*. 2009;33:1075-1080.

15. Chen Y, Wang X, Chen D, Miao J, Liao X, Yu F. Posterior hybrid technique for ossification of the posterior longitudinal ligament associated with segmental instability in the cervical spine. *J Spinal Disord Tech*. 2014;27:240-244.

16. Chen Y, Wang X, Yang H, Miao J, Liu X, Chen D. Upregulated expression of PERK in spinal ligament fibroblasts from the patients with ossification of the posterior longitudinal ligament. *Eur Spine J*. 2014;23:447-454.

17. Chiba K, Kato Y, Tsuzuki N, et al. Computer-assisted measurement of the size of ossification in patients with ossification of the posterior longitudinal ligament in the cervical spine. *J Orthop Sci*. 2005;10:451-456.

18. Chiba K, Ogawa Y, Ishii K, et al. Long-term results of expansive open-door laminoplasty for cervical myelopathy—average 14-year follow-up study. *Spine (Phila Pa 1976)*. 2006;31:2998-3005.

19. Chiba K, Yamamoto I, Hirabayashi H, et al. Multicenter study investigating the postoperative progression of ossification of the posterior longitudinal ligament in the cervical spine: a new computer-assisted measurement. *J Neurosurg Spine*. 2005;3:17-23.

20. Chikuda H, Seichi A, Takeshita K, et al. Acute cervical spinal cord injury complicated by preexisting ossification of the posterior longitudinal ligament: a multicenter study. *Spine (Phila Pa 1976)*. 2011;36:1453-1458.

21. Choi JH, Shin JJ, Kim TH, Shin HS, Hwang YS, Park SK. Does intramedullary signal intensity on MRI affect the surgical outcomes of patients with ossification of posterior longitudinal ligament? *J Korean Neurosurg Soc*. 2014;56:121-129.

22. Choi S, Lee SH, Lee JY, et al. Factors affecting prognosis of patients who underwent corpectomy and fusion for treatment of cervical ossification of the posterior longitudinal ligament: analysis of 47 patients. *J Spinal Disord Tech*. 2005;18:309-314.

23. Epstein N. The surgical management of ossification of the posterior longitudinal ligament in 51 patients. *J Spinal Disord*. 1993;6:432-454.

24. Eun JP, Ma TZ, Lee WJ, et al. Comparative analysis of serum proteomes to discover biomarkers for ossification of the posterior longitudinal ligament. *Spine (Phila Pa 1976)*. 2007;32:728-734.

25. Fujimori T, Iwasaki M, Nagamoto Y, et al. Three-dimensional measurement of growth of ossification of the posterior longitudinal ligament. *J Neurosurg*. 2012;16:289-295.

26. Fujimori T, Iwasaki M, Nagamoto Y, et al. Three-dimensional measurement of intervertebral range of motion in ossification of the posterior longitudinal ligament: are there mobile segments in the continuous type? *J Neurosurg Spine*. 2012;17:74-81.

27. Fujimori T, Iwasaki M, Okuda S, et al. Long-term results of cervical myelopathy due to ossification of the posterior longitudinal ligament with an occupying ratio of 60% or more. *Spine (Phila Pa 1976)*. 2014;39:58-67.

28. Fujimori T, Le H, Hu SS, et al. Ossification of the posterior longitudinal ligament of the cervical spine in 3161 patients: a CT-based study. *Spine (Phila Pa 1976)*. 2015;40:E394-E403.

29. Fujimori T, Le H, Ziewacz JE, Chou D, Munnamani PV. Is there a difference in range of motion, neck pain, and outcomes in patients with ossification of posterior longitudinal ligament versus those with cervical spondylosis, treated with plated laminoplasty? *Neurosurg Focus*. 2013;35(1):E9.

30. Fujimura Y, Nakamura M, Toyama Y. Influence of minor trauma on surgical results in patients with cervical OPLL. *J Spinal Disord*. 1998;11:16-20.

31. Fujiya M, Kaneda K, Homma S. The follow-up study of the nonsurgically treated patients with cervical ossified posterior longitudinal ligament [in Japanese]. *Hokkaido J Orthop Trauma Surg*. 1977;22(1-2):1-8.

32. Fujiyoshi T, Yamazaki M, Okawa A, et al. Static versus dynamic factors for the development of myelopathy in patients with cervical ossification of the posterior longitudinal ligament. *J Clin Neurosci*. 2010;17:320-324.

33. Goto S, Kita T. Long-term follow-up evaluation of surgery for ossification of the posterior longitudinal ligament. *Spine (Phila Pa 1976)*. 1995;20:2247-2256.

34. Gu Y, Chen L, Dong RB, Feng Y, Yang HL, Tang TS. Lamino-plasty versus conservative treatment for acute cervical spinal cord injury caused by ossification of the posterior longitudinal ligament after minor trauma. *Spine*. 2014;14:344-352.

35. Hanakita J, Suwa H, Namura S, Mizuno M, Ootsuka T, Asahi M. The significance of the cervical soft disc herniation in the ossification of the posterior longitudinal ligament. *Spine (Phila Pa 1976)*. 1994;19:412-418.

36. Harsh GR, Sypert GW, Weinstein PR. Cervical spine stenosis secondary to ossification of the posterior longitudinal ligament. *J Neurosurg*. 1987;67:349-357.

37. Hasegawa K, Homma T. Morphologic evaluation and surgical simulation of ossification of the posterior longitudinal ligament using helical computed tomography with three-dimensional and multiplanar reconstruction. *Spine (Phila Pa 1976)*. 1997;22:537-543.

38. He Z, Zhu H, Ding L, Xiao H, Chen D, Xue F. Association of NP1 polymorphism with postoperative progression of ossification of the posterior longitudinal ligament in Chinese patients. *Genet Mol Res*. 2013;12:4648-4655.
Iwasaki M, Okuda S, Miyauchi A, et al. Surgical strategy for ossified posterior longitudinal ligament. *Neurol Med Chir (Tokyo)*. 1997;37:173-175.

Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. *Spine (Phila Pa 1976)*. 1981;6:354-364.

Hirai N, Ikata T, Murase M, Morita T, Katoh S. Bone mineral density of the lumbar spine in patients with ossification of the posterior longitudinal ligament of the cervical spine. *J Spinal Disord.* 1995;8:337-341.

Hori T, Kawaguchi Y, Kimura T. How does the ossification area of the posterior longitudinal ligament thicken following cervical laminoplasty? *Spine (Phila Pa 1976)*. 2007;32:E551-E556.

Hori T, Kawaguchi Y, Kimura T. How does the ossification area of the posterior longitudinal ligament progress after cervical laminoplasty? *Spine (Phila Pa 1976)*. 2006;31:2807-2812.

Hossam M, Shabaan M, Rabab MAE. Median cervical corpectomy for cervical myelopathy associated with ossified posterior longitudinal ligament. *Trends Med Res.* 2013;8:1-15.

Isu T, Minoshima S, Mabuchi S. Anterior decompresion and fusion using bone grafts obtained from cervical vertebral bodies for ossification of the posterior longitudinal ligament of the cervical spine: technical note. *Neurosurgery*. 1997;40:866-869.

Ito K, Minoshima S, Mabuchi S, Nakayama N. Surgical treatment for ossification of the posterior longitudinal ligament of the cervical spine [in Japanese]. *No Shinkei Geka.* 1994;22:839-844.

Ito K, Yukawa Y, Ito K, et al. Dynamic changes in the spinal cord cross-sectional area in patients with myelopathy due to cervical ossification of posterior longitudinal ligament. *Spine J.* 2015;15:461-466.

Ito K, Yukawa Y, Machino M, Kato F. Spinal cord cross-sectional area during flexion and extension in the patients with cervical ossification of posterior longitudinal ligament. *Eur Spine J.* 2013;22:2564-2568.

Ito K, Yukawa Y, Machino M, Kobayakawa A, Kato F. Range of motion determined by multidetector-row computed tomography in patients with cervical ossification of the posterior longitudinal ligament. *Nagoya J Med Sci.* 2015;77:221-228.

Iwasaki M, Kawaguchi Y, Kimura T, Yonenobu K. Long-term results of expansive laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine: more than 10 years follow up. *J Neurosurg Spine.* 2002;96:180-189.

Iwasaki M, Okuda S, Miyaiuchi A, et al. Surgical strategy for cervical myelopathy due to ossification of the posterior longitudinal ligament: part 1: clinical results and limitations of laminoplasty. *Spine (Phila Pa 1976).* 2007;32:647-653.

Iwasaki M, Okuda S, Miyaiuchi A, et al. Surgical strategy for cervical myelopathy due to ossification of the posterior longitudinal ligament: part 2: advantages of anterior decompresion and fusion over laminoplasty. *Spine (Phila Pa 1976).* 2007;32:654-660.
70. Kawaguchi H, Kurokawa T, Machida H, et al. Roentgenological manifestation of ossification of the posterior longitudinal ligament in the cervical spine causing severe spinal canal stenosis—a group comparison with and without marked spinal cord dysfunction [in Japanese]. Nihon Seikeigeka Gakkai Zasshi. 1991;65:173-180.

71. Kawano H, Handa Y, Ishii H, Sato K, Oku T, Kubota T. Surgical treatment for ossification of the posterior longitudinal ligament of the cervical spine. J Spinal Disord. 1995;8:145-150.

72. Kim K, Isu T, Sugawara A, Matsumoto R, Isobe M. Anterior decompensation via a wide transvertebral approach and a ceramic insert in a patient with cervical degenerative disease. Surg Neurol. 2007;67:127-133.

73. Kim TJ, Bae KW, Uhm WS, Kim TH, Joo KB, Jun JB. Prevalence of ossification of the posterior longitudinal ligament of the cervical spine. J Orthop Surg Res. 2014;9:e106598.

74. Kim K, Isu T, Sugawara A, et al. Treatment of cervical OPLL by anterior fusion using autologous vertebral bone grafts. Acta Neurochir (Wien). 2009;151:1549-1555.

75. Kim B, Shin HC, Kim KN, Yi S, Shin DA, Ha Y. Surgical outcome and prognostic factors of anterior decompensation and fusion for cervical compressive myelopathy due to ossification of the posterior longitudinal ligament. Spine J. 2015;15:875-884.

76. Kimura S, Furukawa K, Yokoyama T, et al. Comparison of cardiovascular parameters between patients with ossification of posterior longitudinal ligament and patients with cervical spondyloptic myelopathy. J Spinal Disord Tech. 2009;22:361-366.

77. Kommu R, Sahu BP, Purohit AK. Surgical outcome in patients with cervical ossified posterior longitudinal ligament: a single institutional experience. Asian J Neurosurg. 2014;9:196-202.

78. Koyanagi I, Iwamuro H, Fujimoto S, Hida K, Iwasaki Y, Houkin K. Spinal canal size in ossification of the posterior longitudinal ligament of the cervical spine. Surg Neurol. 2004;62:286-291.

79. Koyanagi I, Iwaki Y, Hida K, Imamura H, Abe H. Magnetic resonance imaging findings in ossification of the posterior longitudinal ligament of the cervical spine. J Neurosurg. 1998;88:247-254.

80. Kudoh H, Furukawa K, Yokoyama T, et al. Genetic differences in the osteogenetic differentiation potency according to the classification of ossification of the posterior longitudinal ligament of the cervical spine. Spine (Phila Pa 1976). 2011;36:951-957.

81. Lee SE, Chung CK, Jahng TA, Kim HJ. Long-term outcome of laminectomy for cervical ossification of the posterior longitudinal ligament. J Neurosurg Spine. 2013;18:465-471.

82. Lin D, Ding Z, Lian K, Hong J, Zhai W. Cervical ossification of the posterior longitudinal ligament: anterior versus posterior approach. Indian J Orthop. 2012;46:92-98.

83. Maruo K, Moriyama T, Tachibana T, et al. The impact of dynamic factors on surgical outcomes after double-door laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine. J Neurosurg Spine. 2014;21:938-943.

84. Matsunaga S, Kukita M, Hayashi K, et al. Pathogenesis of myelopathy in patients with ossification of the posterior longitudinal ligament. J Neurosurg. 2002;96(2 suppl):168-172.

85. Kawaguchi Y, Matsumoto M, Iwasaki M, et al. New classification system for ossification of the posterior longitudinal ligament using CT images. J Orthop Sci. 2014;19:530-536.

86. Kawaguchi Y, Nakano M, Yasuda T, Seki S, Hori T, Kimura T. Anterior decompressive surgery after cervical laminoplasty in patients with ossification of the posterior longitudinal ligament. Spine J. 2014;14:955-963.

87. Kawaguchi Y, Urushisaki A, Seki S, Hori T, Asanuma Y, Kimura T. Evaluation of ossification of the posterior longitudinal ligament by three-dimensional computed tomography and magnetic resonance imaging. Spine J. 2011;11:927-932.

88. Kudo H, Furukawa K, Yokoyama T, et al. Genetic differences in the osteogenetic differentiation potency according to the classification of ossification of the posterior longitudinal ligament of the cervical spine. Spine (Phila Pa 1976). 2011;36:951-957.

89. Kudo H, Yokoyama T, Tsushima E, et al. Interobserver and intraobserver reliability of the classification and diagnosis for ossification of the posterior longitudinal ligament of the cervical spine. Eur Spine J. 2013;22:205-210.

90. Kwon SY, Shin JJ, Lee JH, Cho WH. Prognostic factors for surgical outcome in spinal cord injury associated with ossification of the posterior longitudinal ligament (OPLL). J Orthop Surg Res. 2015;10:94.

91. Lei T, Shen Y, Wang LF, Cao JM, Ding WY, Ma QH. Cerebrospinal fluid leakage during anterior approach cervical spine surgery for severe ossification of the posterior longitudinal ligament: prevention and treatment. Orthop Surg. 2012;4:247-252.

92. Li JM, Zhang Y, Ren Y, et al. Uniaxial cyclic stretch promotes osteogenic differentiation and synthesis of BMP2 in the C3H10T1/2 cells with BMP2 gene variant of rs2273073 (T/G). PLoS One. 2014;9:e106598.

93. Lin D, Ding Z, Lian K, Hong J, Zhai W. Cervical ossification of the posterior longitudinal ligament: anterior versus posterior approach. Indian J Orthop. 2012;46:92-98.
posterior longitudinal ligament. J Neurosurg. 2002;97(2 suppl):172-175.
97. Matsunaga S, Sakou T, Nakanisi K. Analysis of the cervical spine alignment following laminoplasty and laminectomy. Spinal Cord. 1999;37:20-24.
98. Matsunaga S, Sakou T, Taketomi E, Nakanisi K. Effects of strain distribution in the intervertebral discs on the progression of ossification of the posterior longitudinal ligaments. Spine (Phila Pa 1976). 1996;21:184-189.
99. Matsunaga S, Sakou T, Taketomi E, Yamaguchi M, Okano T. The natural course of myelopathy caused by ossification of the posterior longitudinal ligament in the cervical spine. Clin Orthop Relat Res. 1994;(305):168-177.
100. Matsunaga S, Nakamura K, Seichi A, et al. Radiographic predictors for the development of myelopathy in patients with ossification of the posterior longitudinal ligament: a multicenter cohort study. Spine (Phila Pa 1976). 2008;33:2648-2650.
101. Matsuoka T, Yamaura I, Kurosa Y, Nakai O, Shindo S, Shinomiya K. Long-term results of the anterior floating method for cervical myelopathy caused by ossification of the posterior longitudinal ligament. Spine (Phila Pa 1976). 2001;26(3):241-248.
102. Mizuno J, Nakagawa H. Outcome analysis of anterior decompressive surgery and fusion for cervical ossification of the posterior longitudinal ligament: report of 107 cases and review of the literature. Neurosurgical focus. 2001;10(4):E6.
103. Mizuno J, Nakagawa H. Anterior decompression for cervical spondylosis associated with an early form of cervical ossification of the posterior longitudinal ligament. Neurosurg Focus. 2002;12(1):E12.
104. Mizuno J, Nakagawa H, Matsuo N, Song J. Dural ossification associated with cervical ossification of the posterior longitudinal ligament: frequency of dural ossification and comparison of neuroimaging modalities in ability to identify the disease. J Neurosurg Spine. 2005;2:425-430.
105. Mizuno J, Nakagawa H. Ossified posterior longitudinal ligament: management strategies and outcomes. Spine J. 2006;6(6 suppl):2828-2885.
106. Mochizuki M, Aiba A, Hashimoto M, Fujiyoshi T, Yamazaki M. Cervical myelopathy in patients with ossification of the posterior longitudinal ligament. J Neurosurg Spine. 2009;10:122-128.
107. Morimoto T, Uranishi R, Nakase H, Kawaguchi S, Hoshida T, Sakaki T. Extensive cervical laminoplasty for patients with long segment OPLL in the cervical spine: an alternative to the anterior approach. J Clin Neurosci. 2000;7:217-222.
108. Morio Y, Nagashima H, Teshima R, Nawata K. Radiological pathogenesis of cervical myelopathy in 60 consecutive patients with cervical ossification of the posterior longitudinal ligament. Spinal Cord. 1999;37:853-857.
109. Morio Y, Yamamoto K, Kishimoto H, Hagino H, Kuranobu K, Kagawa T. Bone mineral density of the radius in patients with ossification of the cervical posterior longitudinal ligament. A longitudinal study. Spine (Phila Pa 1976). 1993;18:2513-2516.
110. Nakamura H. A radiographic study of the progression of ossification of the cervical posterior longitudinal ligament: the correlation between the ossification of the posterior longitudinal ligament and that of the anterior longitudinal ligament [in Japanese]. Nihon Seikeigeka Gakkai Zasshi. 1994;68:725-736.
111. Ogawa Y, Chiba K, Matsumoto M, et al. Long-term results after expansive open-door laminoplasty for the segmental-type of ossification of the posterior longitudinal ligament of the cervical spine: a comparison with nonsegmental-type lesions. J Neurosurg Spine. 2005;3:198-204.
112. Ogawa Y, Toyama Y, Chiba K, et al. Long-term results of expansive open-door laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine. J Neurosurg Spine. 2004;1:168-174.
113. Ohtsuka K, Terayama K, Yamagihara M. A radiological population study on the ossification of the posterior longitudinal ligament in the spine. Arch Orthop Trauma Surg. 1987;106:89-93.
114. Onari K, Akiyama N, Kondo S, Toguchi A, Mihara H, Tsuchiya T. Long-term follow-up results of anterior interbody fusion applied for cervical myelopathy due to ossification of the posterior longitudinal ligament. Spine (Phila Pa 1976). 2001;26:488-493.
115. Onishi E, Sakamoto A, Murata S, Matsushita M. Risk factors for acute cervical spinal cord injury associated with ossification of the posterior longitudinal ligament. Spine (Phila Pa 1976). 2012;37:660-666.
116. Ono K, Ota H, Tada K. Ossified posterior longitudinal ligament: a clinicopathologic study. Spine (Phila Pa 1976). 1977;2:126-138.
117. Ono S, Uwada O, Tamura S, Watanabe K. CT findings of ossification of the posterior longitudinal ligament (OPLL), with special emphasis on the relationship to clinical symptoms [in Japanese]. Nippon Igaku Hoshasen Gakkai Zasshi. 1989;49:1517-1524.
118. Otake S, Matsuo M, Nishizawa S, Sano A, Kuroda Y. Ossification of the posterior longitudinal ligament: MR evaluation. AJNR Am J Neuroradiol. 1992;13:1059-1067.
119. Park JY, Chin DK, Kim KS, Cho YE. Thoracic ligament ossification in patients with cervical ossification of the posterior longitudinal ligaments: tandem ossification in the cervical and thoracic spine. Spine (Phila Pa 1976). 2008;33:E407-E410.
120. Sakai K, Okawa A, Takahashi M, et al. Five-year follow-up evaluation of surgical treatment for cervical myelopathy caused by ossification of the posterior longitudinal ligament: a prospective comparative study of anterior decompression and fusion with floating method versus laminoplasty. Spine (Phila Pa 1976). 2012;37:367-376.
121. Sakai K, Okawa A, Takahashi M, et al. Five-year follow-up evaluation of surgical treatment for cervical myelopathy caused by ossification of the posterior longitudinal ligament: a prospective comparative study of anterior decompression and fusion with floating method versus laminoplasty. Spine (Phila Pa 1976). 2012;37:367-376.
122. Sasaki E, Ono A, Yokoyama T, et al. Prevalence and symptom of ossification of posterior longitudinal ligaments in the Japanese general population. J Orthop Sci. 2014;19:405-411.
123. Sato R, Uchida K, Kobayashi S, et al. Ossification of the posterior longitudinal ligament of the cervical spine: histopathological findings around the calcification and ossification front. J Neurosurg Spine. 2007;7:174-183.
124. Sato S, Kaneda K, Fujiya M. Follow-up study of the surgically treated cases with cervical myelopathy due to ossification of the posterior longitudinal ligaments [in Japanese]. *Hokkaido J Orthop Trauma Surg.* 1977;22(1-2):9-16.

125. Seichi A, Hoshino Y, Kimura A, et al. Neurological complications of cervical laminoplasty for patients with ossification of the posterior longitudinal ligament—a multi-institutional retrospective study. *Spine (Phila Pa 1976).* 2011;36:E998-E1003.

126. Seichi A, Hoshino Y, Ohnishi I, Kurokawa T. The role of calcium metabolism abnormalities in the development of ossification of the posterior longitudinal ligament of the cervical spine. *Spine (Phila Pa 1976).* 1992;17(3 suppl):S30-S32.

127. Sohn S, Chung CK. Increased bone mineral density and decreased prevalence of osteoporosis in cervical ossification of the posterior longitudinal ligament: a case-control study. *Calcif Tissue Int.* 2013;92:28-34.

128. Sohn S, Chung CK, Yun TJ, Sohn CH. Epidemiological survey of ossification of the posterior longitudinal ligament in an adult Korean population: three-dimensional computed tomographic observation of 3,240 cases. *Calcif Tissue Int.* 2014;94:613-620.

129. Son S, Lee SG, Yoo CJ, Park CW, Kim WK. Single stage circumferential cervical surgery (selective anterior cervical corpectomy with fusion and laminoplasty) for multilevel ossification of the posterior longitudinal ligament with spinal cord ischemia on MRI. *J Korean Neurosurg Soc.* 2010;48:335-341.

130. Sugrue PA, McClendon J Jr, Halpin RJ, Liu JC, Koski TR, Ganju A. Surgical management of cervical ossification of the posterior longitudinal ligament: natural history and the role of surgical decompression and stabilization. *Neurosurg Focus.* 2011;30(3):E3.

131. Sun Q, Hu H, Zhang Y, et al. Do intramedullary spinal cord changes in signal intensity on MRI affect surgical opportunity and approach for cervical myelopathy due to ossification of the posterior longitudinal ligament? *Eur Spine J.* 2011;20:1466-1473.

132. Takami T, Ohata K, Goto T, et al. Lift-up laminoplasty for myelopathy caused by ossification of the posterior longitudinal ligament of the cervical spine. *Neural India.* 2004;52:59-63.

133. Tateiwa Y, Kamimura M, Itoh H, et al. Multilevel subtotal corpectomy and interbody fusion using a fibular bone graft for cervical myelopathy due to ossification of the posterior longitudinal ligament. *J Clin Neurosci.* 2003;10:199-207.

134. Tominaga S. The effects of intervertebral fusion in patients with myelopathy due to ossification of the posterior longitudinal ligament of the cervical spine. *Int Orthop.* 1980;4:183-191.

135. Tomita K, Nomura S, Umeda S, Baba H. Cervical laminoplasty to enlarge the spinal canal in multilevel ossification of the posterior longitudinal ligament with myelopathy. *Arch Orthop Trauma Surg.* 1988;107:148-153.

136. Uchida K, Nakajima H, Sato R, et al. Multivariate analysis of the neurological outcome of surgery for cervical compressive myelopathy. *J Orthop Sci.* 2005;10:564-573.

137. Wang H, Liu D, Yang Z, et al. Association of bone morphogenetic protein-2 gene polymorphisms with susceptibility to ossification of the posterior longitudinal ligament of the spine and its severity in Chinese patients. *Eur Spine J.* 2008;17:956-964.

138. Wang H, Yang ZH, Liu DM, Wang L, Meng XL, Tian BP. Association between two polymorphisms of the bone morphogenetic protein-2 gene with genetic susceptibility to ossification of the posterior longitudinal ligament of the cervical spine and its severity. *Chin Med J.* 2008;121:1806-1810.

139. Wang MY, Thambuswamy M. Ossification of the posterior longitudinal ligament in non-Asians: demographic, clinical, and radiographic findings in 43 patients. *Neurosurg Focus.* 2011;30(3):E4.

140. Wang PN, Chen SS, Liu HC, Fuh JL, Kuo BI, Wang SJ. Ossification of the posterior longitudinal ligament of the spine. A case-control risk factor study. *Spine (Phila Pa 1976).* 1999;24:142-144.

141. Wang X, Chen D, Yuan W, Zhang Y, Xiao J, Zhao J. Anterior surgery in selective patients with massive ossification of posterior longitudinal ligament of cervical spine: technical note. *Eur Spine J.* 2012;21:314-321.

142. Wei W, He HL, Chen CY, et al. Whole exome sequencing implicates PTCH1 and COL17A1 genes in ossification of the posterior longitudinal ligament of the cervical spine in Chinese patients. *Genet Mol Res.* 2014;13:1794-1804.

143. Wong JJ, Leung OC, Yuen MK. Questionable adequacy of magnetic resonance for the detection of ossification of the posterior longitudinal ligament of the cervical spine. *Hong Kong J Radiol.* 2010;14:78-83.

144. Yamashita T, Yokogushi K, Ono N, Annen S, Owada O. Analysis of bone density in cases of cervical OPLL using the microdensitometry method [in Japanese]. *Hokkaido J Orthop Trauma Surg.* 1988;32:43-48.

145. Yamashita Y, Takahashi M, Matsuno Y, et al. Spinal cord compression due to ossification of ligaments: MR imaging. *Radiology.* 1990;175:843-848.

146. Yamauchi T, Taketomi E, Matsunaga S, Sakou T. Bone mineral density in patients with ossification of the posterior longitudinal ligament in the cervical spine. *J Bone Miner Metab.* 1999;17:296-300.

147. Yang H, Lu X, Wang X, et al. A new method to determine whether ossified posterior longitudinal ligament can be resected completely and safely: spinal canal “Rule of Nine” on axial computed tomography. *Eur Spine J.* 2015;24:1673-1680.

148. Yang H, Yang L, Chen D, Wang X, Lu X, Yuan W. Implications of different patterns of “double-layer sign” in cervical ossification of the posterior longitudinal ligament. *Eur Spine J.* 2015;24:1631-1639.

149. Yang HS, Chen DY, Lu XH, et al. Choice of surgical approach for ossification of the posterior longitudinal ligament in combination with cervical disc hernia. *Eur Spine J.* 2010;19:494-501.

150. Yang DY, Wang-Ch Y, Lee CS, Chou DY. Ossification of the posterior cervical longitudinal ligament. *Acta Neurochir (Wien).* 1992;115(1-2):15-19.

151. Yang SC, Yu SW, Tu YK, Niu CC, Chen LH, Chen WJ. Open-door laminoplasty with suture anchor fixation for cervical...
myelopathy in ossification of the posterior longitudinal ligament. J Spinal Disord Tech. 2007;20:492-498.

152. Yasui N, Ono K, Yamaura I. Immunohistochemical localization of types I, II, and III collagens in the ossified posterior longitudinal ligament of the human cervical spine. Calcif Tissue Int. 1983;35:159-163.

153. Yonemori K, Imamura T, Ishidou Y, et al. Bone morphogenetic protein receptors and activin receptors are highly expressed in ossified ligament tissues of patients with ossification of the posterior longitudinal ligament. Am J Pathol. 1997;150:1335-1347.

154. Yoshii T, Yamada T, Hirai T, et al. Dynamic changes in spinal cord compression by cervical ossification of the posterior longitudinal ligament evaluated by kinematic computed tomography myelography. Spine (Phila Pa 1976). 2014;39:113-119.

155. Yonemura N, Nagata K, Muraki S, et al. Prevalence and progression of radiographic ossification of the posterior longitudinal ligament and associated factors in the Japanese population: a 3-year follow-up of the ROAD study. Osteoporos Int. 2014;25:1089-1098.

156. Yuan W, Zhu Y, Liu X, et al. Postoperative three-dimensional cervical range of motion and neurological outcomes in patients with cervical ossification of the posterior longitudinal ligament: cervical laminoplasty versus laminectomy with fusion. Clin Neurol Neurosurg. 2015;134:17-23.

157. Yukawa Y, Ito K, MacHino M, et al. Dynamic changes in the spinal cord cross-sectional area in patients with myelopathy due to cervical ossification of posterior longitudinal ligament. Spine J. 2015;15:461-466.

158. Zhao X, Xue Y, Pan F, et al. Extensive laminectomy for the treatment of ossification of the posterior longitudinal ligament in the cervical spine. Arch Orthop Trauma Surg. 2012;132:203-209.

159. Min JH, Jang JS, Lee SH. Significance of the double-layer and single-layer signs in the ossification of the posterior longitudinal ligament of the cervical spine. J Neurosurg Spine. 2007;6:309-312.

160. Del Conte L, Tassinari T, Trucco M, Serrato O, Badino R. Ossification of the posterior longitudinal ligament (OPLL) in the cervical spine. Clinical, neuroradiological and neurophysiological study on 9 cases. Ital J Neurol Sci. 1992;13:767-780.

161. Jayakumar PN, Kohli VR, Vasudev MK, Srikanth SG. Ossification of the posterior longitudinal ligament of the cervical spine in Asian Indians—a multiracial comparison. Clin Neurol Neurosurg. 1996;98:142-148.

162. Nakashita T, Toyokura Y, Mannen T. Osteosis of the cervical posterior ligament—clinical findings and radiologic features. Clin Neurol. 1967;7:607-618.

163. Nose T, Egashira T, Enomoto T, Maki Y. Ossification of the posterior longitudinal ligament: a clinico-radiological study of 74 cases. J Neurol Neurosurg Psychiatry. 1987;50:321-326.

164. Fujiyoshi T, Yamazaki M, Kawabe J, et al. A new concept for making decisions regarding the surgical approach for cervical ossification of the posterior longitudinal ligament: the K-line. Spine (Phila Pa 1976). 2008;33:E990-E993.

165. Nagashima H, Nanjo Y, Tanida A, Miha A, Takeda C, Teshima R. Influence of spinous process spacers on surgical outcome of laminoplasty for OPLL. Orthopedics. 2013;36:e494-e500.

166. Chen J, Song D, Wang X, Shen X, Li Y, Yuan W. Is ossification of posterior longitudinal ligament an enthesopathy? Int Orthop. 2011;35:1511-1516.

167. Terada A, Sakou T, Matsunaga S, Taketomi E, Kouichi O. 3-Dimensional computed tomography of ossification of the spinal ligament. Clin Orthop Relat Res. 1997;(336):137-142.

168. Matsuyama Y, Kawakami N, Yanase M, et al. Cervical myelopathy due to OPLL: clinical evaluation by MRI and intraoperative spinal sonography. J Spinal Disord Tech. 2004;17:401-404.

169. Epstein NE. Identification of ossification of the posterior longitudinal ligament extending through the dura on preoperative computed tomographic examinations of the cervical spine. Spine (Phila Pa 1976). 2001;26:182-186.

170. Epstein NE. Wound-peritoneal shunts: part of the complex management of anterior dural lacerations in patients with ossification of the posterior longitudinal ligament. Surg Neurol. 2009;72:630-634.

171. Sim J, Wright CC. The kappa statistic in reliability studies: use, interpretation, and sample size requirements. Phys Ther. 2005;85:257-268.