

Advancements in clinical practices of computed tomography imaging and its implications on surgical strategies for the management of cervical ossification of the posterior longitudinal ligament: A systematic review

SAGE Open Medicine

Volume 13: 1–14

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DOI: 10.1177/20503121251331795

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Abstract

Objectives: This systematic review examines advancements in computed tomography imaging-based classification systems and their implications for surgical decision-making in managing cervical ossification of the posterior longitudinal ligament.

Methods: This study is a systematic review. A comprehensive search of PubMed, MEDLINE, and Scopus databases identified relevant studies published from January 2010 to July 2024. The search utilized keywords including “ossification of the posterior longitudinal ligament,” “cervical,” “spine,” “computed tomography,” and “classification.” Studies meeting predefined inclusion criteria focused on computed tomography imaging for diagnosing and surgically managing cervical ossification of the posterior longitudinal ligament. The study adhered to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, and the ROBINS-I tool was used for risk of bias assessment.

Results: Sixteen studies were included, demonstrating that computed tomography imaging enhances diagnostic precision and classification reliability for cervical ossification of the posterior longitudinal ligament. Comparative analysis across studies revealed consistent trends in computed tomography-based classification improving surgical decision-making, particularly influencing anterior approaches such as anterior controllable antedisplacement and fusion. However, moderate to severe risks of bias were identified in some studies, primarily due to confounding variables and deviations from intended interventions. Additionally, computed tomography imaging’s role in prevalence studies has been expanded by incorporating, which highlights its epidemiological significance. The review also discusses the disadvantages of computed tomography, including radiation exposure and cost implications.

Conclusions: Computed tomography imaging is a crucial modality for diagnosing and managing cervical ossification of the posterior longitudinal ligament, offering superior lesion classification and guiding surgical decision-making. Future research should refine classification systems and integrate multimodal imaging approaches to enhance diagnostic and therapeutic precision.

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Keywords

Ossification of the posterior longitudinal ligament, cervical, classification systems, surgical strategies, surgical outcomes

Received: 5 February 2025; accepted: 17 March 2025

Introduction

Ossification of the posterior longitudinal ligament (OPLL) is a pathological condition characterized by abnormal calcification of the posterior longitudinal ligament within the spinal column, predominantly affecting the cervical region.¹⁻⁴ This disorder often leads to severe clinical manifestations, including myelopathy and radiculopathy, which arises due to compression of the spinal cord and nerve roots. Consequently, the accurate diagnosis and effective management of OPLL are critical in preventing neurological deterioration and improving patient outcomes.^{1,4}

Historically, the classification of OPLL has relied heavily on plain radiographic methods, particularly lateral radiographs.^{1,2} However, the intricate three-dimensional architecture of OPLL frequently renders radiographs insufficient for a thorough evaluation.^{2,3} The advent of advanced imaging modalities, especially computed tomography (CT), has instigated a significant shift in the diagnostic approach to OPLL. CT imaging surpasses traditional methods by offering superior visualization of the ossified lesions' extent and morphology, enabling more precise classification and facilitating customized surgical planning.^{1,2,4}

Surgical intervention remains a cornerstone in the treatment of OPLL, particularly for patients presenting with significant neurological deficits. The complexity of OPLL demands a meticulous approach to spinal surgery, where the choice of surgical techniques, whether anterior, posterior, or a combined approach, is informed by the precise characterization of the ossified lesion. Recent studies have introduced various CT-based classification systems that provide a more nuanced assessment of OPLL.^{1,2,5,6} These systems have been pivotal in guiding surgical decision-making and tailoring the surgical approach to achieve optimal decompression and stabilization of the cervical spine.^{1,2,5,6} Despite these advancements, there remains an unmet need for a standardized classification system that is universally applicable across diverse patient populations and adaptable to various surgical contexts.

This systematic review endeavors to critically analyze the extant literature on CT imaging-based classification systems for cervical OPLL and their implications for surgical strategy formulation and treatment outcomes. By synthesizing evidence from multiple studies, this review seeks to elucidate the progress achieved in this domain, identify persisting gaps in knowledge, and suggest avenues for future research that could further refine surgical techniques and improve patient care.

Methods

This study is a systematic review conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, focusing on advancements in CT imaging and its implications on surgical strategies for managing cervical OPLL.⁷

Literature search strategy

A literature search was conducted using PubMed, MEDLINE, and Scopus databases to identify relevant studies published between January 1, 2010, and July 31, 2024. The search strategy employed a combination of Medical Subject Headings (MeSH) terms and keywords, including "OPLL," "Cervical," "Spine," "CT," and "Classification." This systematic review adhered to the PRISMA guidelines⁷ to ensure a comprehensive and unbiased search. Additionally, reference lists of relevant articles were manually screened to capture any studies that might have been missed during the database search.

Inclusion and exclusion criteria

The inclusion criteria for the review encompassed randomized controlled trials (RCTs) and observational cohort studies, without limitations on study design, and including both retrospective and prospective studies. Only articles written in English with accessible abstracts and full texts were considered. Studies excluded from the review were case reports, reviews, meta-analyses, and studies without available abstracts or full texts. Non-English language articles were also excluded. Two reviewers conducted the study selection process independently, with discrepancies resolved through discussion and, if necessary, by consultation with a third reviewer.

Data extraction

Data extraction was performed using a standardized data extraction form, recording details such as authors, year of publication, journal, study title, objectives, specific patient groups, methods, sample size, nationality, type of study, classification systems used, measurement parameters, statistical tools, performance, accuracy, results, and outcomes. To ensure data accuracy, a second independent reviewer cross-verified all extracted data, resolving any inconsistencies through discussion or, if required, consultation with a third reviewer.

Risk of bias assessment

The risk of bias in nonrandomized studies was assessed using the ROBINS-I tool (Cochrane, London, UK, Risk Of Bias In Non-randomized Studies – of Interventions),⁸ which evaluates biases across domains such as confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of reported results. For RCTs, the Cochrane Risk of Bias Assessment Tool (RoB 2)⁹ was employed, evaluating domains including the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was rated as having a low, moderate, serious, or critical risk of bias. The risk of bias assessment was conducted independently by two reviewers, with discrepancies resolved through discussion or, when necessary, by involving a third reviewer.

Data synthesis

The extracted data were synthesized and analyzed to compare the outcomes of the various studies. A systematic synthesis was performed due to the heterogeneity of the study designs, patient populations, and outcome measures. The findings were then categorized based on the primary focus of the studies, including the classification systems used, imaging modalities evaluated, surgical strategies, and surgical outcomes reported.

Results

Literature search results

The systematic literature search identified a total of 630 records from the MeSH, MEDLINE, and Scopus databases after duplicate records and the article Language in non-English were removed. Titles were reviewed, leading to the exclusion of 365 records that were deemed irrelevant to the study's focus. Abstract assessments excluded 283 reports, including 157 review articles, 32 meta-analyses, 5 letters to the editor, and 89 case reports. During the full-text assessment, an additional 108 reports were excluded due to various reasons, such as not being related to cervical spine studies, not involving CT-scan studies, or focusing on artificial intelligence, expert opinions, or consensus studies. Ultimately, 16 studies were selected as the best match for inclusion in the review. These studies were chosen based on their relevance to clinical practices, CT imaging, and surgical strategies for managing cervical OPLL in spine surgery. The study selection process is summarized in the PRISMA flow diagram (Figure 1), which includes the reasons for exclusions at each stage.

The demographic data of this systematic review

This systematic review included 16 studies focusing on the advancements in CT imaging-based classification systems for cervical OPLL and their implications for surgical strategies. The studies were conducted across various countries, with a majority from Asia, particularly Japan and South Korea. The study designs included prospective case studies, retrospective reviews, and comparative analyses. The sample sizes ranged from 16 to 2917 patients, highlighting the study scope, and design diversity. The demographic data of the studies are included in this review (Table 1).

Risk of bias analysis

All 16 studies were nonrandomized studies. Therefore, risk of bias was evaluated and analyzed by the ROBINS-I tool.⁸ The risk of bias analysis for the included studies revealed that the majority of studies, such as those by Chang et al.,¹ Kawaguchi et al.,² Fujimori et al.,³ Kudo et al.,⁴ Izumi et al.,⁵ Kawaguchi et al.,⁶ Yang et al.,¹⁰ Choi et al.,¹¹ Fujimori et al.,¹² Bakhsh et al.,¹⁵ Asari et al.,¹⁷ and Wang et al.,¹⁹ were found to have a moderate overall risk of bias. However, a few studies, including those by Lee et al.,¹³ Hirai et al.,¹⁴ Zhai et al.,¹⁶ and Tsai et al.¹⁸ exhibited an overall severe risk of bias, primarily due to issues such as deviations from intended interventions or confounding factors. These findings underscore the need for careful interpretation of the results, especially in studies with a higher risk of bias (Table 2 and Figure 2).

Clinical practices of CT imaging and surgical strategies

The results of this systematic review included 16 studies that focused on various aspects of using CT imaging to classify, diagnose, and manage cervical OPLL. The studies assessed the reliability of different imaging modalities, the development and validation of classification systems, and the implications for surgical decision-making and outcomes (Table 3).

Inter- and intraobserver reliability. Chang et al.¹ examined the inter- and intraobserver reliability of OPLL classification using different imaging techniques. The study found that while lateral radiographs showed fair reliability, the use of 2D and 3D CT significantly improved reliability, particularly for continuous-type OPLL. Similarly, Kudo et al.⁴ reported that including CT images enhanced the reliability of OPLL classification compared to radiographs alone.

Classification and visualization. Both of Kawaguchi et al.^{2,6} studies reported the classification and visualization of OPLL using CT imaging. Kawaguchi et al.² highlighted the

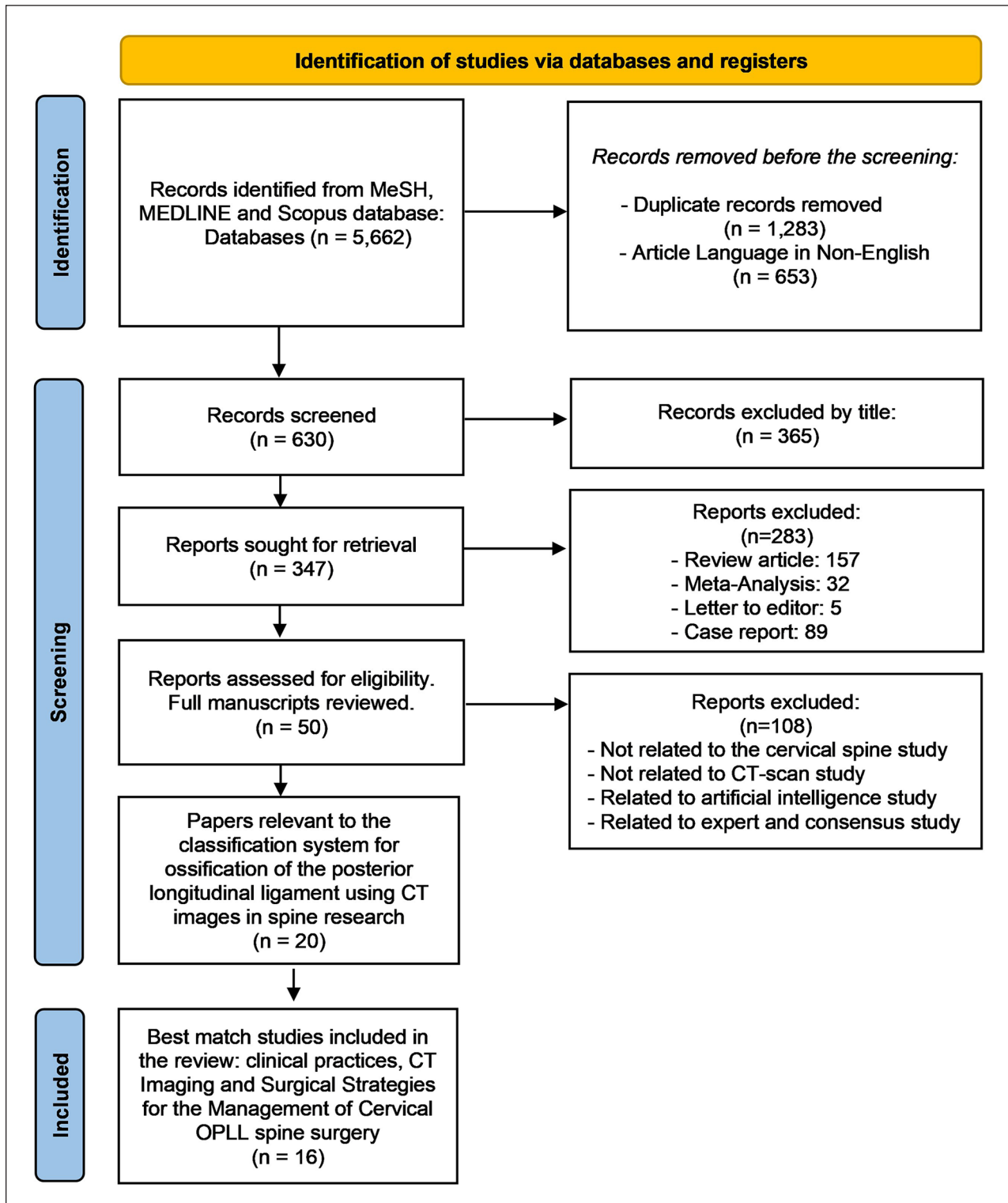


Figure 1. PRISMA flow diagram in this systematic study.

superiority of 3D CT over lateral radiography in visualizing OPLL and emphasized the importance of MRI in detecting spinal cord compression. Kawaguchi et al.⁶ proposed a new

CT-based classification system that demonstrated good reliability for identifying different OPLL types, offering a more detailed and accurate method for OPLL assessment.

Table 1. The demographic data of the studies for this systematic review.

No.	Authors	Published year	Journal	Sample size	Nationality	Type of study
1	Chang et al. ¹	2010	Clinical Orthopedic Surgery	108	South Korea	Prospective study
2	Kawaguchi et al. ²	2011	The Spine Journal	55	Japan	Prospective study
3	Fujimori et al. ³	2012	Journal of Neurosurgery: Spine	20	Japan	Prospective study
4	Kudo et al. ⁴	2013	European Spine Journal	16	Japan	Prospective study
5	Izumi et al. ⁵	2013	European Spine Journal	20	Japan	Prospective study
6	Kawaguchi et al. ⁶	2014	Journal of Orthopedic Science	144	Japan	Prospective study
7	Yang et al. ¹⁰	2015	European Spine Journal	268	China	Retrospective study
8	Choi et al. ¹¹	2015	Clinical Orthopedic Surgery	241	South Korea	Retrospective study
9	Fujimori et al. ¹²	2016	Spine (Phila Pa 1976)	1500	Japan	Cross-sectional study
10	Lee et al. ¹³	2018	The Spine Journal	34	South Korea	Retrospective study (multicenter)
11	Hirai et al. ¹⁴	2018	BMC Musculoskeletal Disorders	322	Japan	Retrospective study (multicenter)
12	Bakhsh et al. ¹⁵	2019	Global Spine Journal	2917	USA	Retrospective study
13	Zhai et al. ¹⁶	2022	Orthopedic Surgery	24	China	Retrospective study
14	Asari et al. ¹⁷	2022	European Spine Journal	61	Japan	Comparative study
15	Tsai et al. ¹⁸	2024	Journal of Medical Imaging and Radiation Oncology	1692	New Zealand	Retrospective study (multicenter)
16	Wang et al. ¹⁹	2024	Orthopedic Surgery	70	China	Prospective study

Table 2. Risk of bias analysis using ROBINS-I tool for nonrandomized control trial study.

No.	Authors	D1 (confounding)	D2 (selection of participants)	D3 (classification of interventions)	D4 (deviations from intended interventions)	D5 (missing data)	D6 (measurement of outcomes)	D7 (selection of the reported result)	Overall
1	Chang et al. ¹	Moderate	Low	Low	Low	Low	Low	Low	Moderate
2	Kawaguchi et al. ²	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
3	Fujimori et al. ³	Moderate	Low	Low	Low	Low	Low	Low	Moderate
4	Kudo et al. ⁴	Moderate	Low	Low	Low	Low	Low	Low	Moderate
5	Izumi et al. ⁵	Moderate	Low	Low	Low	Low	Low	Low	Moderate
6	Kawaguchi et al. ⁶	Moderate	Low	Low	Low	Low	Low	Low	Moderate
7	Yang et al. ¹⁰	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate
8	Choi et al. ¹¹	Moderate	Low	Low	Low	Low	Low	Low	Moderate
9	Fujimori et al. ¹²	Moderate	Low	Low	Low	Low	Low	Low	Moderate
10	Lee et al. ¹³	Moderate	Low	Low	Serious	Low	Low	Low	Serious
11	Hirai et al. ¹⁴	Serious	Low	Low	Moderate	Low	Low	Low	Serious
12	Bakhsh et al. ¹⁵	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
13	Zhai et al. ¹⁶	Moderate	Low	Low	Serious	Low	Low	Low	Serious
14	Asari et al. ¹⁷	Moderate	Low	Low	Low	Low	Low	Low	Moderate
15	Tsai et al. ¹⁸	Serious	Low	Low	Moderate	Low	Low	Low	Serious
16	Wang et al. ¹⁹	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate

Surgical decision-making. Several studies explored the impact of imaging and classification on surgical strategies. Yang et al.¹⁰ classified different patterns of the “double-layer sign” in OPLL and found that certain patterns were strongly associated with cerebrospinal fluid (CSF) leakage after anterior decompression surgery. These findings suggest that the “Double-Layer Sign” is a crucial factor in surgical decision-making. Wang et al.¹⁹ compared the outcomes of Hybrid anterior controllable antedisplacement and fusion (ACAF) and laminoplasty in patients with multilevel cervical OPLL, finding that Hybrid ACAF provided better recovery and maintenance of cervical lordosis and sagittal plane balance, albeit with longer operation times and higher rates of dysphagia and hoarseness.

Progression and risk factors. Studies by Lee et al.¹³ and Zhai et al.¹⁶ examined the progression of cervical OPLL and its associated risk factors. Lee et al.¹³ identified that disc involvement and segmental range of motion (ROM) were significant risk factors for cervical OPLL progression after laminoplasty. Zhai et al.¹⁶ found that thoracic OPLL progressed faster in thickness and cross-sectional area (CSA) compared to cervical OPLL, with notable demographic associations, such as age, gender, and BMI.

Epidemiology and prevalence. The prevalence and characteristics of cervical OPLL in various populations were studied by Fujimori et al.,¹² Bakhsh et al.,¹⁵ and Tsai et al.¹⁸ Fujimori et al.¹² reported a high prevalence and significant concomitance of

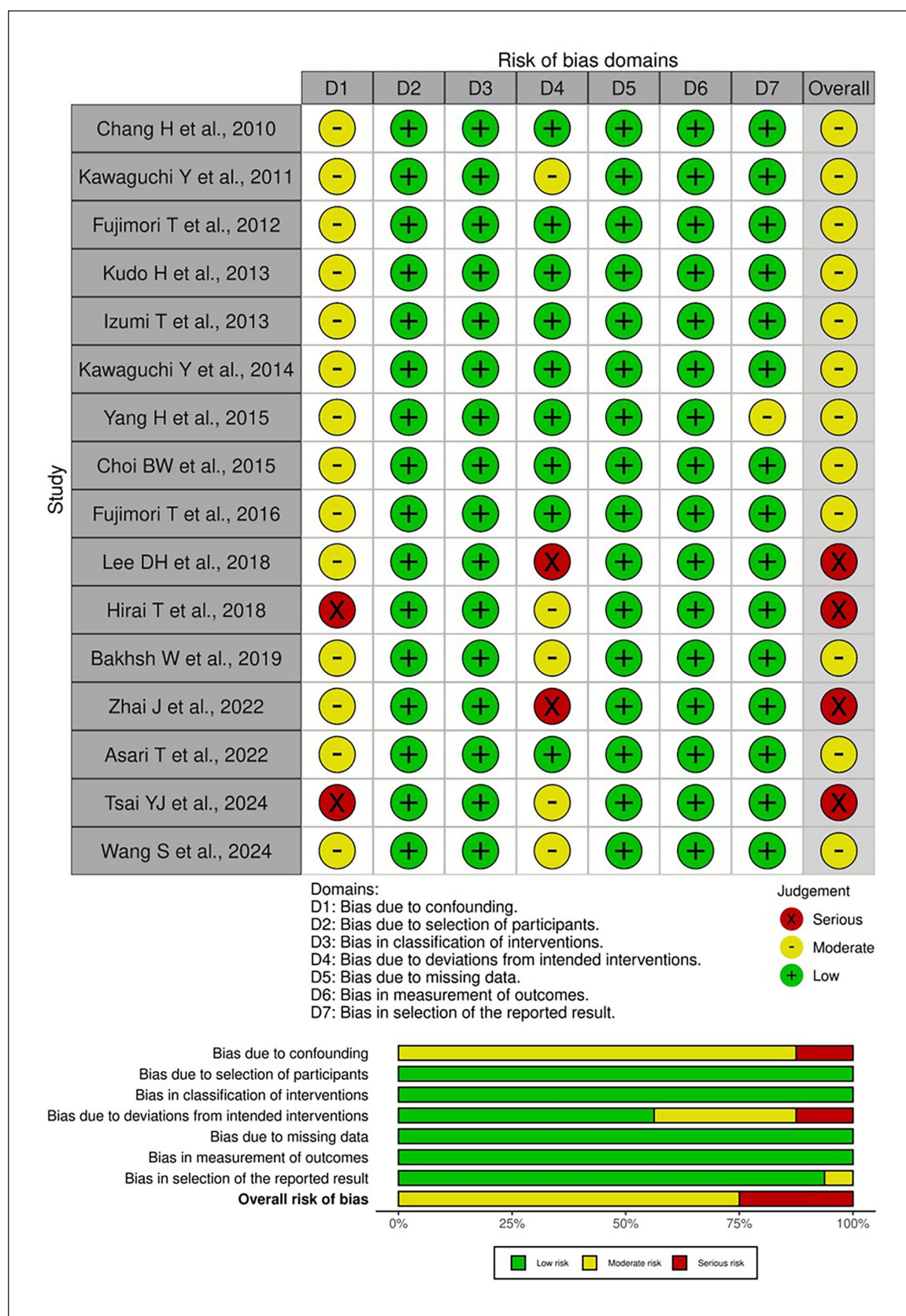


Figure 2. Risk of bias summary for nonrandomized controlled trials, assessed using the risk of bias in nonrandomized studies of interventions ROBINS-I tool (Cochrane, London, UK).

Table 3. The summary of clinical practices of CT imaging and surgical strategies in cervical OPLL for this systematic review.

No.	Authors	Title	Objective	Focus group of study	Methods	Base of classification	Measurement/parameters	Statistical	Performance and accuracy	Results and outcome
1	Chang et al. ¹	Inter- and intraobserver variability of a cervical OPLL classification using reconstructed CT images	To examine inter- and intraobserver reliability of OPLL classification using CT images	Patients diagnosed with cervical OPLL	Five spine surgeons reviewed lateral radiographs, axial CT, 2-D, and 3-D reconstructed CT images of OPLL patients twice	Tsuyama's system using lateral radiographs and CT	Inter- and intraobserver reliability	Kappa values	Fair for lateral radiographs, good to excellent for 2D and 3D CT	Reliability improved with 2D and 3D CT images, particularly for continuous-type OPLL
2	Kawaguchi et al. ²	Evaluation of ossification of the posterior longitudinal ligament by three-dimensional computed tomography and magnetic resonance imaging	To evaluate 3D CT and MRI in visualizing and classifying OPLL	Patients diagnosed with cervical OPLL	3D CT imaging and MRI of OPLL lesions compared to lateral radiography	3D CT and MRI	Visualization and classification of OPLL	Not specified	3D CT is superior to lateral radiography for visualizing OPLL. MRI provided additional details on spinal cord compression	3D CT is better at classifying OPLL and MRI is important for detecting spinal cord compression
3	Fujimori et al. ³	Three-dimensional measurement of intervertebral range of motion in ossification of the posterior longitudinal ligament: are there mobile segments in the continuous type?	To evaluate intervertebral ROM in continuous-type OPLL using functional CT	Patients with continuous-type OPLL	Functional CT in AP flexion and right/left axial rotation to evaluate intervertebral ROM	Functional CT	Intervertebral ROM	Not specified	Bridging ossifications had minimal ROM, while nonbridging types had significant ROM	Continuous-type OPLL with nonbridging had notable intervertebral motion
4	Kudo et al. ⁴	Interobserver and intraobserver reliability of the classification and diagnosis for ossification of the posterior longitudinal ligament of the cervical spine	To assess inter- and intraobserver reliability of OPLL classification using radiographs and CT images	Patients with cervical OPLL	Observers classified patients based on radiographs and CT images measuring reliability over two sessions	Radiographs and CT	Inter- and intraobserver reliability	Kappa values	Reliability improved with the inclusion of CT images in the classification process	CT images improved classification reliability compared to radiographs alone
5	Izumi et al. ⁵	Three-dimensional evaluation of volume change in ossification of the posterior longitudinal ligament of the cervical spine using computed tomography	To evaluate volume changes in OPLL using a 3D CT analysis method	Patients with OPLL followed conservatively	Patients were scanned twice with 3D CT over at least a 1-year interval. MIMICS® software is used to calculate ossification volume	3D CT	Ossification volume, annual rate of progression	Not specified	Mean annual ossification volume increase of 3.33%	The 3D CT method allowed precise measurement of OPLL volume changes over time
6	Kawaguchi et al. ⁶	New classification system for ossification of the posterior longitudinal ligament using CT images	To propose a new CT-based classification system for cervical OPLL	Patients diagnosed with cervical OPLL by plain radiographs	Sagittal and axial CT images were used to classify OPLL into three new systems: A (bridge/nonbridge), B (lesion levels), and axial (central/lateral lesions)	CT imaging	Intra- and interrater reliability	Leiss' kappa coefficient	The new CT classification system showed good reliability for identifying different OPLL types	The CT classification system provides a more detailed and reliable method for OPLL assessment
7	Yang et al. ¹⁰	Implications of different patterns of "double-layer sign" in cervical ossification of the posterior longitudinal ligament	To classify double-layer sign patterns in OPLL and assess their clinical implications	Patients with cervical OPLL undergoing anterior corpectomy	Retrospective analysis of CT images to classify double-layer sign patterns and correlate them with surgical outcomes, particularly CSF leakage	Double-layer sign patterns	CSF leakage rates, surgical outcomes	Correlation analysis	Type C double-layer sign almost always resulted in CSF leakage after anterior decompression	The pattern of the double-layer sign is an important factor in OPLL surgical decision-making

(Continued)

Table 3. (Continued)

No.	Authors	Title	Objective	Focus group of study	Methods	Base of classification	Measurement/parameters	Statistical	Performance and accuracy	Results and outcome
8	Choi et al. ¹¹	Significance of intramedullary high signal intensity on magnetic resonance imaging in patients with cervical ossification of the posterior longitudinal ligament	To analyze the relationship between IMHS on MRI and clinical symptoms in OPLL patients	Patients with cervical OPLL	Retrospective analysis of MRI, CT, and radiographic data to correlate IMHS with clinical symptoms, OPLL occupying ratio, and ROM	MRI and CT	IMHS presence, OPLL occupying ratio, ROM, JOA scores	t-Test, Chi-square test	IMHS on MRI was associated with myelopathy and higher OPLL occupying ratios but not with ROM	IMHS presence indicates myelopathic symptoms in OPLL patients and is correlated with the occupying ratio
9	Fujimori et al. ¹²	Prevalence, concomitance, and distribution of the spinal ligaments: results of whole spine CT scans in 1500 Japanese patients	To investigate the prevalence, concomitance, and distribution of spinal ligament ossifications using whole spine CT	Patients undergoing PET-CT scans as part of a preventive health check	Cross-sectional study using whole spine CT to detect and classify various types of spinal ligament ossifications	Whole spine CT	Prevalence, distribution, and concomitance of spinal ligament ossifications	Not specified	High prevalence of various ligament ossifications, with significant concomitance across types and spinal levels	Whole spine CT provided accurate detection of ligament ossifications with notable concomitance
10	Lee et al. ¹³	Radiological risk factors for progression of ossification of posterior longitudinal ligament following laminoplasty	To evaluate the progression of cervical OPLL after laminoplasty and identify risk factors	Patients with cervical myelopathy secondary to OPLL undergoing laminoplasty	Retrospective analysis of radiological data to classify OPLL and assess its progression after laminoplasty	Radiographs and CT	OPLL thickness, disc space involvement, ROM	t-Test, Chi-square test	Types 2- and 3-disc involvement with ROM > 5° were significant risk factors for OPLL progression	Classification of OPLL by disc involvement is useful for predicting progression after laminoplasty
11	Hirai et al. ¹⁴	Distribution of ossified spinal lesions in patients with severe ossification of the posterior longitudinal ligament and prediction of ossification at each segment based on the cervical OP index classification: a multicenter study (JOSL CT study)	To investigate the distribution of OPLL in the thoracolumbar spine in patients with cervical OPLL	Patients diagnosed with cervical OPLL	A multicenter study across 20 institutions in Japan to evaluate the prevalence and distribution of OPLL in the thoracic and lumbar spine	Cervical OPLL diagnosis	Distribution and severity of thoracolumbar OPLL	Not specified	Thoracolumbar OPLL was most common at T1 in men and T3/4 in women, with more diffuse distribution in severe cases	Thoracolumbar OPLL distribution differs by gender, with more diffuse patterns in severe cases
12	Bakhsh et al. ¹⁵	Cervical ossification of the posterior longitudinal ligament: a computed tomography-based epidemiological study of 2917 patients	To identify the prevalence and characteristics of cervical OPLL in a large sample using CT scans	Patients receiving cervical spine CT imaging in a level-I emergency department	Retrospective review of cervical spine CT scans to diagnose and classify OPLL, with demographic data analysis	Cervical spine CT	Prevalence, OPLL type, demographic associations	t-Test, Chi-square test	OPLL prevalence of 2.5%, with segmental type most common and significant association with diabetes	The segmental OPLL type is most common, with significant demographic associations, particularly with diabetes

(Continued)

Table 3. (Continued)

No.	Authors	Title	Objective	Focus group of study	Methods	Base of classification	Measurement/parameters	Statistical	Performance and accuracy	Results and outcome
13	Zhai et al. ¹⁶	Progression of spinal ligament ossification in patients with thoracic myelopathy	To evaluate the rate of progression in thickness and cross-section area (CSA) of ossification in thoracic myelopathy	Patients with thoracic myelopathy and spinal ligament ossification	Retrospective review of CT images to measure thickness and CSA of ossified ligaments, with demographic and clinical data analysis	Thoracic myelopathy with spinal ligament ossification	Ossification thickness, CSA, demographic factors	t-Test, correlation analysis	Faster ossification growth in females, older patients, and those with lower BMI, with thoracic OPLL progressing faster than cervical OPLL	Thoracic OPLL progresses faster in thickness and CSA compared to cervical OPLL, with significant demographic associations
14	Asari et al. ¹⁷	Usefulness of digital tomosynthesis in diagnosing cervical ossification of the posterior longitudinal ligament: a comparative study with other imaging modalities	To compare the accuracy of digital tomosynthesis (DTS) with radiography and CT for diagnosing and classifying cervical OPLL	Patients with cervical OPLL and cervical spondylotic myelopathy	Comparative study of DTS, radiography, and CT images evaluated by specialists and residents, with intra- and interobserver reliability assessed	DTS, radiography, CT	Diagnostic accuracy, intra- and interobserver reliability	Kappa values	DTS may be an alternative to CT for diagnosing and classifying cervical OPLL by specialists, but caution is needed with residents	DTS shows promise as an alternative to CT for OPLL diagnosis by specialists, but CT remains the gold standard
15	Tsai et al. ¹⁸	Prevalence of ossification of the posterior longitudinal ligament (OPLL) in the Pacific populations in Auckland, New Zealand: A retrospective multicenter study	To investigate the prevalence of OPLL in a mixed demographic region, especially in the Pacific Island population	Patients undergoing cervical spine CT in Auckland, New Zealand	Retrospective assessment of CT scans from multiple centers, with demographic data collection and analysis of OPLL prevalence by ethnicity and associated conditions	Cervical spine CT	OPLL prevalence by ethnicity, association with diabetes and DISH	Chi-square test	Higher OPLL prevalence in Pacific Islander, Asian, and Māori populations compared to Europeans, with significant associations with diabetes and DISH	Pacific Islander populations have a significantly higher prevalence of OPLL, with notable associations with diabetes and DISH
16	Wang et al. ¹⁹	The CT classification of multilevel cervical ossification of the posterior longitudinal ligament to guide hybrid anterior controllable antedisplacement and fusion versus posterior laminoplasty	To compare the efficacy and safety of hybrid ACAF with laminoplasty for multilevel OPLL	Patients with multilevel cervical OPLL	A prospective study comparing hybrid ACAF and laminoplasty outcomes using CT classification of OPLL, with follow-up for at least 1 year	CT classification	JOA score, recovery rate, VAS, NDI, C2-C7 Cobb angle, SVA, complications	t-Test, nonparametric test	Hybrid ACAF had better recovery, cervical lordosis maintenance, and sagittal plane balance, but longer operation time and more dysphagia/hoarseness	Hybrid ACAF is a precise alternative to laminoplasty for multilevel OPLL, with superior outcomes but longer operation time

OPLL: ossification of the posterior longitudinal ligament; CT: computed tomography; MRI: magnetic resonance imaging; AP: anteroposterior; CSA: cross-sectional area; DISH: diffuse idiopathic skeletal hyperostosis; VAS: visual analog scale; NDI: neck disability index; SVA: sagittal vertical axis; CSF: cerebrospinal fluid; DTS: digital tomosynthesis; 2D: two-dimensional; 3D: three-dimensional; K-line: a modified line connecting the midpoints of the spinal canal at C2 and C7 on sagittal CT myelography; MIMICS®: Software for medical image processing.

various ligament ossifications in Japanese patients. Bakhsh et al.¹⁵ observed a prevalence of 2.5% in a large cohort of patients in the USA, with the segmental type being most common and significantly associated with diabetes. Tsai and Doyle¹⁸ found that the Pacific Islander population in Auckland, New Zealand, had a significantly higher prevalence of cervical OPLL, with strong associations with diabetes and diffuse idiopathic skeletal hyperostosis (DISH).

Discussion

CT imaging has emerged as the preferred modality due to its ability to provide high-resolution assessments of ossified lesions, leading to enhanced classification accuracy and surgical planning. Recent advances in CT-based classification systems have significantly impacted on surgical decision-making. Particularly, ACAF and laminoplasty strategies have been influenced by CT-based classifications, improving surgical outcomes. This systematic review aims to synthesize current literature regarding CT imaging-based classification systems for cervical OPLL, discussing their clinical implications and surgical strategies. According to the studies reviewed, it is evident that while traditional radiographic methods provide some insights into cervical OPLL, they often fall short of capturing the complexity and variability of the ossified lesions. The introduction and validation of 2D and 3D CT imaging has addressed these limitations, offering clinicians a more nuanced understanding of cervical OPLL morphology, which is crucial for diagnosis and surgical planning. One of the significant contributions of this review is the emphasis on the reliability of cervical OPLL classification systems when enhanced by CT imaging. Studies such as those by Chang et al.¹ and Kudo et al.⁴ demonstrated that the inter- and intraobserver reliability significantly improves with CT imaging compared to lateral radiographs alone. This improvement is particularly noteworthy for continuous-type OPLL, where traditional imaging modalities often struggle to provide consistent and reliable results. These findings highlight the necessity of incorporating CT imaging into routine clinical practice for a more accurate and reproducible OPLL classification, which can ultimately guide better patient management.

Integrated findings and comparative analysis across studies that are one of the key strengths of this systematic review. While each study individually assessed different aspects of CT imaging in OPLL, a consistent trend emerged wherein CT-based classifications led to improved inter- and intraobserver reliability. For instance, Chang et al.¹ and Kudo et al.⁴ demonstrated enhanced classification reliability with 3D CT compared to lateral radiographs. Similarly, Kawaguchi et al.⁶ proposed a CT-based classification system that better characterized different OPLL types, improving clinical decision-making. These findings emphasize the importance of integrating multiple study outcomes to provide a holistic understanding of CT imaging's role in OPLL management.

The development of new classification systems based on CT imaging, as proposed by Kawaguchi et al.,^{2,6} further

illustrates the potential of CT imaging in refining our understanding of cervical OPLL. These classification systems not only offer a more detailed characterization of the lesion but also provide a framework for assessing the severity and progression of the disease. This level of detail is indispensable for tailoring surgical interventions to individual patient needs, which is critical given the varying patterns and clinical implications of cervical OPLL.

Impact of CT imaging on surgical decision-making are critical gap in previous reviews was the explicit discussion of how CT imaging classification directly influences surgical approaches, such as ACAF. In this review, we address this issue by integrating findings from Yang et al.¹⁰ and Wang et al.,¹⁹ which revealed that certain CT-based classifications correlate with CSF leakage risks in anterior decompression surgeries. Surgical decision-making is another area where CT imaging has been shown to be particularly beneficial.^{1,20} The classification of double-layer signs by Yang et al.¹⁰ is a prime example of how CT imaging can inform surgical approaches, particularly in predicting the risk of complications such as CSF leakage. This predictive capability underscores the importance of detailed preoperative imaging in optimizing surgical outcomes and minimizing complications. This highlights the necessity of preoperative CT assessments in selecting the most appropriate surgical approach.

Risk factor of cervical OPLL of this review also sheds light on the progression of cervical OPLL and the factors that influence its development. Studies by Lee et al.¹³ and Zhai et al.¹⁶ suggest that factors such as disc involvement, ROM, and demographic variables like age, gender, and BMI play significant roles in the progression of cervical OPLL. The ability to identify these risk factors through detailed imaging and classification allows for more proactive management strategies, potentially slowing the progression of the disease and improving long-term outcomes.

Epidemiological insights and prevalence studies that strengthen the epidemiological aspect of OPLL, we have now included Singh et al.,²¹ which reported the prevalence and demographic associations of OPLL based on 2500 CT scans. Their findings contribute to a broader understanding of regional variations and associated comorbidities, such as diabetes and DISH. Moreover, the epidemiological studies included in this review, such as those by Fujimori et al.^{3,12} and Tsai and Doyle,¹⁸ highlight the varying prevalence of OPLL across different populations and the associated demographic and health factors, such as diabetes and DISH. These findings contribute to a broader understanding of cervical OPLL and emphasize the need for targeted screening and management strategies in populations at higher risk. This addition improves the review's comprehensiveness in discussing both diagnostic and prevalence aspects of CT imaging. We comprehensively summarize advancements in CT imaging, surgical strategy, and decision-making for cervical OPLL in Table 4.

This study's limitation is its reliance on imaging modalities, particularly CT scans, as the primary diagnostic tool for

Table 4. A comprehensive summary of advancements in CT imaging to manage cervical OPLL.

Parameter	Advancement	Implication	Role in clinical practice	Advantages	Disadvantages	Surgical approach and decision-making
CT imaging	Enhanced visualization with 3D and functional CT imaging	Improved accuracy in diagnosing and classifying OPLL, allowing for precise assessment of lesion morphology	Critical for accurate diagnosis: essential in providing detailed anatomical information crucial for preoperative planning	- Superior to traditional radiography in visualizing complex OPLL lesions - Facilitates better surgical planning	- Higher radiation exposure compared to standard imaging - Requires access to advanced imaging technology	Supports detailed assessment of lesion morphology, guiding the selection between anterior, posterior, or hybrid approaches
Classification systems	Development of new CT-based classification systems (e.g., bridge/nonbridge, lesion levels)	Offers a more detailed and reliable method for assessing OPLL types, leading to standardized diagnoses	Standardizing treatment approaches: crucial for consistent diagnosis, guiding appropriate treatment choices	- Improves inter- and intraobserver reliability, enhancing clinical consistency - Aids in tailored treatment planning	- Requires specialized training for accurate classification - May not be universally available in all practice settings	Facilitates accurate classification of OPLL, influencing the decision for anterior or posterior surgical approaches
Surgical decision-making	Use of modified K-line classification and CT-based classification systems	Assists in selecting the most appropriate surgical approach (anterior vs posterior) based on individual patient anatomy and disease characteristics	Guiding surgical strategy: central to determining the best approach (anterior, posterior, or hybrid) based on specific OPLL features	- Allows for personalized surgical strategies, potentially improving patient outcomes - Reduces the risk of surgical complications by optimizing approach selection	- Complex decision-making process that requires high-level expertise - Incorrect classification may lead to suboptimal outcomes	The modified K-line and CT classifications guide the choice of anterior versus posterior approach, or when to employ a hybrid approach for complex cases
Inter- and intraobserver reliability	Improved reliability with the use of 2D and 3D CT images	Enhances consistency in OPLL diagnosis and classification among different observers	Ensuring diagnostic consistency: important for reducing variability in clinical assessments	- Decreases variability in diagnosis, leading to more uniform patient management. - Enhances the reliability of clinical studies and outcomes	- Dependence on high-quality imaging technology, which may not be accessible in all settings	Consistent classification and diagnosis are critical for standardizing the surgical approach across different surgeons
Volume measurement	Use of 3D CT and advanced software for precise ossification volume measurement	Allows for detailed monitoring of OPLL progression, aiding in long-term treatment planning	Monitoring disease progression: essential for tracking the progression of OPLL and adjusting treatment strategies accordingly	- Enables early detection of disease progression, allowing timely interventions - Provides quantitative data for research and clinical decision-making	- High cost and need for technical expertise in data interpretation - Limited availability of advanced imaging software	Helps to monitor disease progression, which may influence decisions regarding the timing of surgery or the need for revision surgery
Double-layer sign	Identification of double-layer sign patterns on CT	Critical for predicting surgical outcomes, particularly the risk of cerebrospinal fluid (CSF) leakage	Risk assessment tool: helps in preoperative planning to anticipate and manage potential complications	- Improves surgical planning by predicting intraoperative risks - Enhances patient safety by allowing surgeons to prepare for potential complications	- Requires specialized imaging interpretation skills - May not be recognized in all radiological practices, limiting its use	Influences the decision to avoid certain surgical approaches (e.g., anterior) if there is a high risk of CSF leakage, favoring alternative strategies

(Continued)

Table 4. (Continued)

Parameter	Advancement	Implication	Role in clinical practice	Advantages	Disadvantages	Surgical approach and decision-making
Surgical strategies	Introduction of hybrid anterior controllable antedisplacement and fusion (hybrid ACAF); combines anterior and posterior approaches, tailored using CT classification and modified K-line	Provides a precise alternative to traditional approaches with improved outcomes in specific patient populations	Tailored surgical interventions: vital for offering patient-specific surgical solutions that address both decompression and stabilization	- Better outcomes in maintaining cervical lordosis and sagittal balance - Effective in complex cases with severe OPLL	- Longer operative times compared to traditional methods, increasing risks of dysphagia and hoarseness - Requires comprehensive preoperative planning and expertise	A hybrid approach is selected based on complex or multilevel OPLL cases that demand both anterior and posterior decompression and stabilization
Demographic and risk factors	Identification of demographic factors affecting OPLL progression, such as age, gender, and BMI	Helps in stratifying patients based on risk, leading to more personalized management strategies	Personalized patient management: key for tailoring follow-up and treatment based on individual risk factors	- Allows for more targeted follow-up and intervention in at-risk populations - Contributes to more effective management of diverse patient groups	- Risk stratification may not be universally applicable, potentially leading to disparities in care	Risk factors are considered in conjunction with imaging findings to decide on the most appropriate surgical intervention, or in some cases, conservative management
Advanced imaging modalities	Exploration of digital tomosynthesis (DTS) as a lower radiation alternative to CT	Shows potential for use in specific clinical scenarios where radiation dose reduction is critical	Supplementary diagnostic tool: can serve as an alternative imaging modality in certain contexts, particularly where CT is not feasible	- Lower radiation exposure compared to CT - Potentially useful in resource-limited settings	- Less established than CT, with potential limitations in diagnostic accuracy - Not yet widely adopted, limiting its utility in standard practice	DTS may be considered for initial assessment or follow-up in settings where CT is less accessible, guiding the need for more detailed imaging

OPLL: ossification of the posterior longitudinal ligament; CT: computed tomography; 3D: three-dimensional; 2D: two-dimensional; ROM: range of motion; CSF: cerebrospinal fluid; MRI: magnetic resonance imaging; AP: anteroposterior; CSA: cross-sectional area; DISH: diffuse idiopathic skeletal hyperostosis; VAS: visual analog scale; NDI: neck disability index; SVA: sagittal vertical axis; DTS: digital tomosynthesis; K-line: a modified line connecting the midpoints of the spinal canal at C2 and C7 on sagittal CT myelography; MIMICS®: software for medical image processing.

cervical OPLL classification and surgical planning. While CT imaging offers enhanced accuracy and reliability, it also exposes patients to higher radiation levels than other imaging techniques, such as MRI. The potential risks associated with repeated radiation exposure, especially in populations requiring frequent imaging, are a concern that warrants careful consideration. Furthermore, this review primarily focuses on studies that used CT imaging to classify and manage cervical OPLL, which may have excluded relevant studies utilizing other imaging modalities or approaches. As a result, the conclusions drawn may not fully encompass the broader spectrum of diagnostic and treatment strategies available for cervical OPLL. Finally, the review is limited by potential bias as studies with negative or nonsignificant findings are less likely to be published and, consequently, included in the analysis. This bias can skew the overall interpretation of the effectiveness and reliability of CT scan in managing cervical OPLL. Lastly, future studies should investigate the cost-effectiveness of different imaging and treatment strategies for OPLL. As healthcare resources are finite, understanding the economic implications of various approaches is essential for ensuring that the most effective and efficient strategies are adopted in clinical practice.

Conclusion

This systematic review highlights the transformative impact of CT imaging in the diagnosis, classification, and surgical management of cervical OPLL. The integration of study findings reinforces the advantages of CT-based classifications in guiding surgical decision-making. Additionally, epidemiological insights provide a broader understanding of OPLL prevalence and risk factors. However, the limitations of CT imaging, including radiation exposure and cost, must be considered when implementing it as a primary diagnostic tool. Future research should focus on refining classification systems, integrating multimodal imaging approaches, and evaluating the cost-effectiveness of different imaging strategies to optimize patient outcomes.

Acknowledgments

The authors would like to thank the Thailand Science Research and Innovation Fund (Fundamental Fund 2025, Grant No. 5013/2567) and the School of Medicine, University of Phayao.

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Statements and declarations

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki and with approval from the Ethics Committee and Institutional Review Board of University of Phayao (Institutional

Review Board (IRB) approval, IRB Number: HREC-UP-HSST 1.1/043/67).

Author contributions/CRedit

Conceptualization: WL and JBP; Methodology: WL, JBP, and WC; Validation: WL, JBP, WC, SS, PS, and CP; Formal analysis: WL, WC, and PS; Investigation: WL, JBP, WC, and PS; Resources: WL, WC, and PS; Data curation: WL, WC, SS, and PS; Writing – original draft preparation: WL, JBP, WC, SS, and PS; Writing – review & editing: WL, JBP, SS, PS, and CP; Visualization: WL, JBP, SS, and CP; Supervision: WL and JBP; Project administration: WL; Funding acquisition: WL. All authors have read and agreed to the published version of the manuscript.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The Thailand Science Research and Innovation Fund (Fundamental Fund 2025, Grant No. 5013/2567) and School of Medicine, University of Phayao, Thailand.

Conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability

The data used in this research were acquired from a public resource.

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