De novo degenerative lumbar scoliosis: a systematic review of prognostic factors for curve progression

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Abstract

Purpose To identify prognostic factors for curve progression in de novo degenerative lumbar scoliosis (DNDLS) by performing a systematic review of the literature.

Methods Studies were selected for inclusion following a systematic search in the bibliographic databases PubMed and EMBASE prior to September 2015 and hand searches of the reference lists of retrieved articles. Two authors independently assessed methodological quality. Data were extracted and presented according to a best evidence synthesis.

Results The literature search generated a total of 2696 references. After removing duplicates and articles that did not meet inclusion criteria, 12 studies were included. Due to the lack of statistical analyses, pooling of data was not possible. Strong evidence indicates that increasing intervertebral disk degeneration, lateral vertebral translation ≥ 6 mm, and an intercrest line through L5 (rather than L4) are associated with DNDLS curve progression. Moderate evidence suggests that apical vertebral rotation Grade II or III is associated with curve progression. For the majority of other prognostic factors, we found limited, conflicting, or

inconclusive evidence. Osteoporosis, a coronal Cobb angle $< 30^\circ$, lumbar lordosis, lateral osteophytes difference of ≥ 5 mm, and degenerative spondylolisthesis have not been shown to be risk factors. Clinical risk factors for progression were not identified.

Conclusions This review shows strong evidence that increased intervertebral disk degeneration, an intercrest line through L5, and apical lateral vertebral translation ≥ 6 mm are associated with DNDLS curve progression. Moderate evidence was found for apical vertebral rotation (Grade II/III) as a risk factor for curve progression. These results, however, may not be directly applicable to the individual patient.

Keywords De novo degenerative lumbar scoliosis · Adult's scoliosis · Prognostic factors · Curve progression · Systematic review

Introduction

The Global Burden of Disease Study has shown that low back pain has remained the leading cause for years lived with disability (YLD) in Western societies in the last two decades [1]. With its lifetime prevalence between 58 and 84 %, low back pain poses substantial burden on global health care [2–4]. A large proportion (85 %) of low back pain is non-specific and has an unknown aetiology [5]. Of the remaining group, one of the known causes for low back pain is scoliosis: a lateral and rotational deformity of the spine with a Cobb angle of more than 10° in the coronal plain [6, 7]. Primary degenerative scoliosis or de novo degenerative lumbar scoliosis (DNDLS) is a condition in which a lumbar scoliotic curve typically develops after the age of 50 in patients who did not have a childhood scoliosis

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[7, 8]. DNDLS causes an increasing burden on society in aging populations, with reduction in health related quality of life due to severe back and leg pain [9, 10]. The aetiology of DNDLS is multifactorial, including genetic predisposition and intervertebral disk degeneration [11–15]. Several studies have reported prevalence rates of 8.3, 8.9, and 13.3 % for adult scoliosis [16–18]. There is sufficient evidence to assume that the growing elderly population will result in an increase in prevalence rates of adult scoliosis [19–22].

DNDLS can cause back and leg pain symptoms in patients, without a history of adolescent idiopathic scoliosis (AIS), and is radiologically characterized by a Cobb angle of 10° or more, and by asymmetrical disk and/or facet arthritis [7, 23–27]. In DNDLS, to date, curve progression is unpredictable. Weinstein and Ponseti 1983 showed that 68 % of curves in AIS as well as adult scoliosis progressed more than 5° after skeletal maturity [28]. In addition, they demonstrated that the progression rate in adult scoliosis is much higher in comparison with AIS. Little else is known about curve progression in DNDLS, and prognostic factors are still undefined. Estimating the risk of curve progression is essential for health care providers to be able to adequately inform patients, and to determine the optimal timing for therapeutic interventions.

The aim of this study was to identify clinical and radiological prognostic factors for curve progression through a systemic review of the literature.

Methods

Search strategy

The review protocol was developed with the use of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and MOOSE guidelines [29, 30]. Relevant published studies involving prognostic factors of progression in DNDLS that were published prior to September 2015 were identified by a systematic search of Pubmed and Embase conducted by an experienced medical information specialist, and backwards citation of obtained articles. Search terms expressing ‘degenerative scoliosis’ and ‘adult scoliosis’ were used in combination with search terms comprising ‘progression’. Keywords used to identify a relevant design were: longitudinal studies, observational studies, prospective studies, cohort studies, retrospective studies, or follow-up studies in the title or in the abstract (Table 1; Supplementary Material). Two reviewers (SSAF and RMH) independently screened the titles, abstracts, and full text articles identified by the literature search. Full text articles were retrieved if the abstract passed the first eligibility screening or provided insufficient information.

Selection criteria

The following inclusion criteria were applied: (1) de novo degenerative lumbar scoliosis, (2) adult scoliosis, (3) curve progression determined by increase in Cobb angle, (4) study population of $N \geq 10$, (5) studies published in the English language, and (6) observational studies. Exclusion criteria were: (1) animal study, (2) biomechanical studies, (3) prior juvenile, adolescent, associated congenital, developmental, or neuromuscular spinal abnormalities, or (4) spinal surgery. All obtained full text articles were reviewed for inclusion independently by SSAF and RMH.

Data extraction

A data-extraction form was developed to obtain the following information: authors, year of publication, definition of DNDLS and curve progression, initial and final Cobb angle, follow-up years, number of patients, gender, researched prognostic factors, including their measurement methods, and statistical analyses method(s).

Methodological quality

Selected papers were subjected to a quality assessment based on the criteria developed by Hayden et al. to assess the methodological quality of studies on prognostic factors [31]. The following domains were evaluated: (1) study participation, (2) study attrition, (3) measurement of prognostic factors (4) adjustment for confounding, (5) measurement of outcomes, and (6) analysis approach. For this study, the aim is not to explore the causality of the association between a specific factor and the outcome, but to estimate the probability of an outcome. Therefore, the Hayden criteria were modified (excluding confounding), as shown in Table 2 (Supplementary Material). These items were scored with 1 point if the item was sufficiently fulfilled. In the case of missing data or insufficient information, 0 points were given. A total quality score was calculated for each study by summing the fulfilled items. High quality was defined as a quality score of ≥ 9 and low quality < 9 . The same approach has also been applied in studies on the prognostic factors of knee and hip arthritis [32, 33]. All included articles were scored independently by SSAF and RMH. In the case of disagreement, the authors arranged a consensus-meeting. When disagreement persisted, a third independent reviewer (TMH) made the final decision.

Analysis

Correlation coefficients were statistically pooled if there was sufficient clinical and statistical homogeneity

regarding the definition of DNDLS and curve progression, study population, measured determinants, and assessed outcomes. In the absence of statistical analysis (correlation or beta coefficients) and heterogeneity in measurement methods of outcomes, region, sample size, and study design, the strength of evidence for prognostic factors was assessed according to the best evidence synthesis (Table 3; Supplementary Material). Level of evidence was based on the updated guidelines by Furlan et al. [34]. Prognostic factors were recorded as consistent if more than 75 % of the studies reported the same direction of association. In reporting the results, the prognostic factors were grouped into patient and radiographic characteristics.

Results

Studies included

The literature search generated a total of 2696 references: 1323 articles in PubMed and 1373 in EMBASE. After removing duplicates of references, 1696 papers remained. Of these 1696 papers, we identified 10 papers that met our inclusion criteria. In addition, two studies were found eligible by backward citation. In total, 12 studies were included (Fig. 1).

Methodological quality

The overall interobserver agreement was 0.88; kappa = 0.74, representing good agreement [35]. Of the 12 included studies, 6 were of high quality (≥ 9 points [13, 36–40]). Most methodological shortcomings concerned lack of adequate follow-up (item F and G), blinding (item H and J), and statistical analysis (item L and M) (Table 4; Supplementary Material).

Study characteristics (Table 1)

The sample size varied between 14 and 318 patients, with a total of 985. Three studies included over 100 patients [6, 18, 41]. The shortest follow-up was 2 years, and the longest was 30 years. In two studies, the follow-up period was not available [11, 18]. A variety in definitions for DNDLS and curve progression was found.

Study results (Tables 2 and 3)

A total of 31 prognostic factors were found, and each of these was classified as either patient or radiographic characteristic. A full overview of the prognostic factors, their measurement methods, and their association with DNDLS curve progression is presented in Tables 2 and 3. Most

authors did not report or perform a correlation analysis of the determinant's association with DNDLS curve progression. Due to a lack of sufficient studies with statistical data, pooling was not possible. In addition, a large heterogeneity between studies in measurement methods, sample sizes, regional differences, and variations in DNDLS and curve progression definitions also precluded statistical pooling of the results. Therefore, it was necessary to summarize each determinant according to the best evidence synthesis to determine the strength of the association with curve progression.

Best evidence synthesis (Fig. 2)

The amount of intervertebral disk degeneration (the ratio of disk height on one decreased side divided by the disk height on the other side) and a lateral vertebral translation of more than ≥ 6 mm were both found to be strongly associated with inducing DNDLS curve progression. Patients with the intercrest line passing through the L5 vertebra had a larger final scoliosis angle than patients with the intercrest line passing through the L4 vertebra [8, 18, 38, 40, 41].

Moderate evidence suggests that more apical vertebral rotation ($>$ Grade II or III Nash and Moe's method [42]) is associated with DNDLS curve progression.

Strong evidence suggests that there is no association between curve progression and osteoporosis, which was measured with several methods (X-ray, biopsy, and DEXA). Other findings with strong evidence for no association were a Cobb angle $< 30^\circ$, lumbar lordosis, and lateral osteophytes difference ≥ 5 mm (measured as the difference between the length of the lateral osteophytes on each side on an AP radiograph).

Moderate evidence was found that there was no association between DNDLS curve progression and age, gender, an intercrest line through the L4 vertebra, apical lateral vertebral translation < 6 mm, and the side of convexity of the scoliosis. Limited evidence was found between degenerative spondylolisthesis and curve progression. For other prognostic factors, limited, inconclusive, or inconsistent evidence was found.

Discussion

The aim of this study was to identify prognostic factors associated with DNDLS curve progression through a systematic review of the literature. After an extensive systematic search of the literature, we identified 12 papers of varying methodological quality. Despite inherent design weaknesses in most papers (mostly related to the difficulty of studying the natural history of a disease), using a

Fig. 1 PRISMA flow chart of the study search and selection [29]

Table 1 Overview of study characteristics

References	Definition DNDLS	Definition curve progress	No. patients (women)	Age, years	Initial Cobb angle	Final Cobb angle	Follow-up, years
Vanderpool et al. [11]	$\geq 7^\circ$	$> 0^\circ$	14 (11)	67	n/a	7° – 53°	n/a
Robin et al. [6]	$\geq 10^\circ$	$\geq 5^\circ$	179 (133)	45–84 ^a	0° – 20°	n/a	7–13
Pritchett et al. [8]	$\geq 10^\circ$	$\geq 10^\circ$	41 (n/a)	69 (50–89)	$\geq 10^\circ$	14° – 60°	12 (10–30)
Korovessis et al. [36]	$\geq 10^\circ$	$\geq 5^\circ$	91 (73)	67 ± 9	16.5°	n/a	3.7 (2–5)
Sapkas et al. [41]	$\geq 10^\circ$	$\geq 10^\circ$	162 (162)	65 (45–84)	$\geq 10^\circ$	12° – 50°	≥ 10
Murata et al. [37]	$\geq 10^\circ$	$\geq 3^\circ$	47 (33)	40–75 ^a	11.6° (10–26.5)	n/a	10 (7–14)
Kobayashi et al. [13]	$\geq 10^\circ$	$\geq 5^\circ$	22 (n/a)	72 (60–95)	n/a	10–18	12 (10–15)
Chin et al. [38]	$\geq 3^\circ$	$> 0^\circ$	24 (17)	68 (50–81)	14.2° (3° – 30°)	21.6° (4° – 46°)	5
Kohno et al. [39]	$\geq 5^\circ$	$> 0^\circ$	27 (20)	63 (48–83)	10.1° (5° – 20°)	15.4° (2° – 39°)	12 (10–18)
Seo et al. [40]	$\geq 10^\circ$	$> 0^\circ$	27 (24)	64 (50–71)	$\geq 10^\circ$	25° (SD, 5.4)	10
Watanuki et al. [43]	$\geq 10^\circ$	$\geq 5^\circ$	33 (23)	75 (57–90)	n/a	10° – 26°	15
Xu et al. [18]	$\geq 10^\circ$	$\geq 5^\circ$	318 (265)	72 ± 10	n/a	10° – 40°	n/a

n/a, not available

^a Age at initial examination

Table 2 Reported patient characteristics as prognostic factor for DNDLS curve progression

Determinants (<i>N</i> patients)	References	Study quality	Measurement methods	Statistical analysis	Association with curve progression
Patient age (<i>N</i> = 482)	Korovessis et al. [36]	High	Continuous (years)	Not provided	o
	Kobayashi et al. [13]	High	Continuous (years)	Not provided	o
	Chin et al. [38]	High	Dichotomous	Not provided	+
	Seo et al. [40]	High	<60 vs 60–70 vs ≥70 years	ρ : 0.14	o
	Xu et al. [18]	Low	<65 vs ≥65 years	$r = 0.021$ $p > 0.12$	o
Female (<i>N</i> = 482)	Korovessis et al. [36]	High		Not provided	o
	Kobayashi et al. [13]	High		Not provided	o
	Chin et al. [38]	High		Not provided	+
	Seo et al. [40]	High		Not provided	o
	Xu et al. [18]	Low		Not provided	o
BMI (<i>N</i> = 340)	Kobayashi et al. [13]	High	kg/m ²	Not provided	o
	Xu et al. [18]	Low		$r = 0.015$	o
Back pain and/or disability (<i>N</i> = 367)	Kobayashi et al. [13]	High	JOA	Not provided	o
	Seo et al. [40]	High	ODI	ρ : 0.6, $p < 0.05$	+
	Seo et al. [40]	High	VAS	ρ : 0.16, $p > 0.05$	o
	Xu et al. [18]	Low	VAS	$r = 0.253$, $p > 0.05$	o
Follow-up period (<i>N</i> = 27)	Kohno et al. [39]	High		$r = 0.006$, $p > 0.05$	o

o, no correlation/no relationship found between prognostic factor and curve progression; +, positive association between prognostic factor and increased curve progression; JOA, Japanese Orthopedic Association Score; ODI, Oswestry Disability Index; VAS, Visual Analog Scale; p , p value; r , correlation coefficient (Pearson's); ρ , correlation coefficient (Spearman's)

qualitative best evidence synthesis, we identified several prognostic factors, all of which were radiological.

In light of the continuously expanding global societal problem of low back pain and degenerative scoliosis related to the aging population, it is important to identify the risks of curve progression to be able to adequately inform our patients about their prognosis, and to streamline the crucial process of shared decision making when identifying the right patients for treatment.

Strong evidence

This review shows strong evidence that the following radiological variables are associated with DNDLS curve progression (Fig. 2):

- Increased intervertebral disk degeneration;
- An intercrest line through L5 (rather than L4 or higher);
- Apical lateral vertebral translation ≥6 mm.

This study found that increasing intervertebral disk degeneration (IDD) measured by disk index (ratio of disk height on the decreased side to the disk height on the opposite side) is strongly associated with DNDLS curve progression (Fig. 2). IDD has also been reported to induce DNDLS. Kobayashi et al. found an increased incidence of DNDLS when there was more than 20 % decrease in asymmetrical unilateral disk height due to degenerative

processes [13]. Interestingly, only one paper (Watanuki et al.) with a small sample size and limited follow-up rate did not identify IDD to be a significant risk factor for curve progression in DNDLS [43].

Based on Pritchett et al. [8], Chin et al. [38], and Sapkas et al. [41], an intercrest line through the L5 vertebra is a strong prognostic factor for curve progression. On the other hand, no curve progression occurred when the intercrest line went through the L4 vertebra. This seems to indicate that in case of a “deep-seated L5” vertebra, and therefore, a deep seated L4–5 disk, curve progression is less likely to occur [8, 38, 40, 41]. A possible explanation for this might be that the less constrained L4–5 disk and L4 vertebra allows L4 to shift and tilt at the lower end of the curve toward the convexity of the curve possibly triggering curve progression [8, 40]. However, it could be possible that on a PA view the coronal projection of L5 would move upward in case of pelvic retroversion. As such, there could be a correlation between a high L5 and pelvic retroversion and sagittal unbalance. To the best of our knowledge, no prior studies have been conducted on the potential correlation between the intercrest line and pelvic retroversion. All studies included in this review did report a consistent method of standing plain radiographs making that it is less likely that these findings could be attributed to an inconsistent method or positioning of the patient during radiographic examination (Table 3). Further research would add

Table 3 Reported radiographic characteristics as prognostic factor for DNDLS curve progression

Determinant (<i>N</i> patients)	References	Study quality	Measurement methods	Statistical analysis	Association with curve progression
Intervertebral disk degeneration (IDD) (<i>N</i> = 151)	Korovessis et al. [36]	High	Ratio of disk height on the decreased side to the disk height on the opposite side	$r = 0.75\text{--}0.8$	+
	Seo et al. [40]	High	Ratio of disk height on one (decreased) side divided by the disk height on the other side (disk index L3; apex)	$\rho: 0.7$	+
	Watanuki et al. [43]	Low	Intervertebral disk angle: between the tangential lines of the inferior endplate of a vertebra and the superior endplate of the next	$p < 0.05$	o
Wedging (<i>N</i> = 269)	Sapkas et al. [41]	Low	Cobb's lateral vertebral wedging method	Not provided	o
	Murata et al. [37]	High	Angle between the line of a vertebra and the line of the immediate caudal vertebra (scoliotic wedging)	Not provided	+
	Seo et al. [40]	High	The sum of segmental wedging angles above and below L3	$\rho: 0.6$	+
	Watanuki et al. [43]	Low	Tilting angle L1–5	$p < 0.05$	o
Vertebral index (<i>N</i> = 22)	Kobayashi et al. [13]	High	The ratio of vertebral height on one (decreased) side divided by vertebral height on the other side at L4 vertebrae	Not provided	o
Bone atrophy (<i>N</i> = 22)	Kobayashi et al. [13]	High	Grade 0–3 ^C	Not provided	o
Osteoporosis (<i>N</i> = 727)	Vanderpool et al. [11]	Low	Bone refraction and biopsy	Not provided	+
	Robin et al. [6]	Low	Bone refraction	Not provided	o
	Sapkas et al. [41]	Low	DPA ¹⁵³ GD to measure BMD	Not provided	o
	Kohno et al. [39]	High	Jikei method (based upon X-ray picture)	$p > 0.05$	o
	Seo et al. [40]	High	DEXA	$p > 0.05$	o
	Xu et al. [18]	Low	DEXA	$r = 0.028$	o
Direction of scoliosis (<i>N</i> = 268)	Vanderpool et al. [11]	Low	Left vs right convex	Not provided	o
	Pritchett et al. [8]	Low	Left vs right convex	Not provided	o
	Sapkas et al. [41]	Low	Left vs right convex	Not provided	o
	Seo et al. [40]	High	Left vs right convex	$p > 0.05$	o
	Chin et al. [38]	High	Left vs right convex	$p < 0.05$	+
Lateral osteophytes diff. >5 mm (<i>N</i> = 27)	Seo et al. [40]	High	The subtraction of length of lateral osteophytes on each side ^B	$p > 0.05$	o
Sagittal balance (<i>N</i> = 82)	Kobayashi et al. [13]	High	Increase in C7 plumbline	Not provided	o
	Watanuki et al. [43]	Low		$p > 0.05$	o
	Seo et al. [40]	High		$\rho: 0.6$	+
Decreased sacral inclination (<i>N</i> = 91)	Korovessis et al. [36]	High	Angle formed by the upper end plate of S1 and the horizontal line	$r = 0.97\text{--}0.99$	o
Pelvic tilt (<i>N</i> = 351)	Watanuki et al. [43]	Low	Pelvic tilt	$p > 0.05$	o
	Xu et al. [18]	Low		$p > 0.05$	o
Thoracic kyphosis (<i>N</i> = 340)	Kobayashi et al. [13]	High	From the upper endplate of T4 to lower endplate of T12	Not provided	o
	Xu et al. [18]	Low		$p > 0.05$	o
Lumbar lordosis (<i>N</i> = 562)	Korovessis et al. [36]	High	Distance from the upper end plate of L1 to lower end plate of L5	$r = 0.89\text{--}0.98$	o
	Kobayashi et al. [13]	High		Not provided	o
	Murata et al. [37]	High		Not provided	+
	Seo et al. [40]	High		$p > 0.05$	o
	Chin et al. [38]	High		Not provided	o
	Watanuki et al. [43]	Low		$p > 0.05$	o
	Xu et al. [18]	Low		$p > 0.05$	o

Table 3 continued

Determinant (<i>N</i> patients)	References	Study quality	Measurement methods	Statistical analysis	Association with curve progression
Sec. compensatory curve at L4–S1	Sapkas et al. [41]	Low	AP and lateral X-ray	Not provided	+
Apical vertebral rotation (<i>N</i> = 354)	Pritchett et al. [8]	Low	Nash and Moe's Grade I or II	Not provided	o
	Sapkas et al. [41]	Low	Nash and Moe's Grade I or II	Not provided	o
	Pritchett et al. [8]	Low	Nash and Moe's Grade II or III	Not provided	+
	Sapkas et al. [41]	Low	Nash and Moe's Grade II or III	Not provided	+
	Kohno et al. [39]	High	Nash and Moe's Grade I–III	$r = 0.502$	+
	Watanuki et al. [43]	Low	Perdriolle and Vidal: $5.2^\circ (\pm 3.3^\circ)$ of L3	$p < 0.05$	+
	Korovessis et al. [36]	High	Perdriolle and Vidal: $15.68^\circ (\pm 7.57^\circ)$ of apical vertebra	$r = 0.74$ – 0.83	o
Intercrest line through L4 (<i>N</i> = 230)	Pritchett et al. [8]	Low	Standing AP and L X-ray	Not provided	o
	Sapkas et al. [41]	Low	Standing AP and L X-ray	Not provided	o
	Seo et al. [40]	High	Standing AP and L X-ray	$p < 0.05$	o
Intercrest line through L5 (<i>N</i> = 572)	Pritchett et al. [8]	Low	Standing AP and L X-ray	Not provided	+
	Sapkas et al. [41]	Low	Standing AP and L X-ray	Not provided	+
	Seo et al. [40]	High	Standing AP and L X-ray	$p < 0.05$	+
	Chin et al. [38]	High	Standing AP and L X-ray	Not provided	+
	Xu et al. [18]	Low	Standing AP and L X-ray	$p < 0.05$	+
Apex L2–3	Sapkas et al. [41]	Low	Standing AP X-ray	Not provided	+
Number of vertebral fractures	Kobayashi et al. [13]	High	Morphometrically ^D	Not provided	o
Spondylolisthesis (<i>N</i> = 189)	Sapkas et al. [41]	Low	Amount of displacement of the upper vertebra divided by the entire width of the vertebra	Not provided	o
	Seo et al. [40]	High	Degenerative listhesis anteriorly, posteriorly or both (sagittal)	$p > 0.05$	o
Apex translation (<i>N</i> = 318)	Xu et al. [18]	Low	The distance from the center of the sacral line to the apical vertebra (mean 22 mm)	$p > 0.05$	o
Lateral vertebral translation ≥ 6 mm (<i>N</i> = 183) or Lateral listhesis of L3 or L4 (apex)	Pritchett et al. [8]	Low	AP and lateral view	Not provided	+
	Korovessis et al. [36]	High	A perpendicular tangential line is drawn on the lateral edge of the apical vertebra on to the line passed on the lower endplate of the vertebra (% lateral spondylolisthesis)	$r = 0.71$ – 0.75	+
	Chin et al. [38]	High		Not provided	+
	Seo et al. [40]	High	The distance from the reference line of laterally translated vertebral body to that of the lower vertebra (lateral listhesis)	$p < 0.05$	+
Lateral vertebral translation < 6 mm (<i>N</i> = 230)	Pritchett et al. [8]	Low	AP and lateral view	Not provided	o
	Sapkas et al. [41]	Low	Standing, using Vernier calipers ^A	Not provided	o
	Seo et al. [40]	High	Distances from the reference line of laterally translated vertebral body to that of the lower vertebra	$p > 0.05$	o
Lateral vertebral translation ≥ 3 mm (=42)	Kohno et al. [39]	High	Not provided	$r = 0.054$	o
	Watanuki et al. [43]	Low	The horizontal distance between two vertical lines which were drawn from the waist to the adjacent vertebra (lateral spondylolisthesis)	$p < 0.05$	+
Harrington factor (<i>N</i> = 118)	Korovessis et al. [36]	High	Cobb angle divided by number of vertebrae in the curve	$r = 0.96$ – 0.99	+
	Kohno et al. [39]	High		$p > 0.05$	o
High Cobb angle ($\geq 30^\circ$) (<i>N</i> = 203)	Pritchett et al. [8]	Low	$\geq 30^\circ$ ($< 30^\circ$ vs $\geq 30^\circ$)	Not provided	+
	Sapkas et al. [41]	Low	$\geq 30^\circ$ ($< 30^\circ$ vs $\geq 30^\circ$)	Not provided	+

Table 3 continued

Determinant (<i>N</i> patients)	References	Study quality	Measurement methods	Statistical analysis	Association with curve progression
Low Cobb angle ($<30^\circ$) (<i>N</i> = 314)	Pritchett et al. [8]	Low	$<30^\circ$ vs $\geq 30^\circ$	Not provided	o
	Sapkas et al. [41]	Low	$<30^\circ$ vs $\geq 30^\circ$	Not provided	o
	Kohno et al. [39]	High	$>5^\circ$ – $<20^\circ$	$p > 0.05$	o
	Seo et al. [40]	High	$<30^\circ$	$p > 0.05$	o
	Chin et al. [38]	High	3° – 15° vs 15° – 30°	Not provided	o
	Watanuki et al. [43]	Low	10° – 26°	Not provided	o

o, no correlation/no relationship found between prognostic factor and curve progression; +, positive association between prognostic factor and increased curve progression; ρ , Spearman correlation; r , Pearson's correlation; AP, anteroposterior; L, lateral; CSA, central spinal axis; JOA, Japanese Orthopedic Association; DEXA, dual energy X-ray absorptiometry

^A Position of the slip vertebrae of the CSA was expressed as the ratio of the distance in mm from the midpoint of the slip vertebra to the CSA divided by the slip diameter in mm

^B The length of lateral osteophytes was the sum of the distances measured from the tip of the osteophyte on the upper and lower endplate to the reference line

^C More than 25 % decrease in anterior vertebral height compared with posterior height, more than 20 % decrease in middle vertebral height compared with anterior or posterior height, or more than 20 % decrease in any vertebral height compared with adjacent vertebrae

^D Grade 0: no modification in vertebral trabecular pattern. Grade 1: decreased transverse trabeculae. Grade 2: decreased vertical trabeculae or unclear vertical and transverse trabeculae

to the understanding of the “depth of L5 seating” and its relationship to pelvic retroversion and curve progression.

Chin et al. observed an approximately two times higher progression rate in patients with LVT ≥ 6 mm compared with LVT < 6 mm [38]. Consistent results on curve progression were found in all studies when the apical vertebra showed LVT ≥ 6 mm compared with < 6 mm [8, 36, 40]. Interestingly, contradicting results were found by Watanuki et al. when including patients with LVT ≥ 3 mm [43]. A possible explanation for this might be the difference in cut-off point used. Note that LVT is a two-dimensional representation of a triaxial deformity consisting of axial rotation and lateral translation toward the convexity of the curve, which occurs predominantly at the L3–4 level [44–46]. Furthermore, it has been hypothesised that vertebral rotation or “rotational instability” may be the initial trigger of DNDLS, and therefore, there might be a causal relationship. Vertebral rotation in combination with lateral spondylolisthesis (lateral vertebral translation) [36, 43, 46] or independently [8, 39, 41] is moderately associated with curve progression (Fig. 2). Only one paper (Korovessis et al.) did not find this relationship, but their deviation from the common grading scale (i.e., the method by Nash and Moe) and relatively short follow-up time (mean 3.7 years; range 2–5 years) might account for this discrepancy [36].

Insufficient evidence

Limited, inconclusive, and conflicting evidence was found for multiple candidate prognostic factors (Fig. 2). The lack of consistent evidence for these potential prognostic

factors, however, should not be interpreted as that these are not associated with curve progression.

Only two low-quality studies were available, and both found a positive correlation between curve magnitude (Cobb angle of $\geq 30^\circ$) and curve progression [8, 41]. A strong relationship between a Cobb angle of $\geq 30^\circ$ and curve progression has already been established in other types of scoliosis. One paper included a 40-year follow-up of AIS patients with a Cobb angle of $\geq 30^\circ$, and showed curve severity to be an important risk factor for curve progression in skeletally mature patients [28]. Similar results are found for idiopathic juvenile scoliosis [47]. When combining this knowledge with the data reported in the two studies on DNDLS, we speculate that a de novo degenerative lumbar scoliosis with a Cobb angle of $\geq 30^\circ$ will most likely progress. Conversely, in milder curves (Cobb angle $< 30^\circ$), there is strong evidence (six studies) that there is no relationship with curve progression [8, 38–41, 43]. However, these findings ought not to be confused with the assumption that low magnitude DNDLS curves of $< 30^\circ$ do not progress at all. By definition, all de novo curves started with a 0° curve, and must have progressed to some degree, even if below 30° . This is in line with Chin et al. and Murata et al. who both demonstrated progression in DNDLS with mild curves $< 30^\circ$, but they did not study the strength of association with curve progression [37, 38].

Although degenerative spondylolisthesis is a common condition in the population of DNDLS, only two studies have investigated the presence of degenerative spondylolisthesis and the specific role that it plays in DNDLS curve progression [40, 41]. It remains unclear whether this

	Associated with DNDLS curve progression	Non-associated with DNDLS curve progression	Insufficient evidence for association with DNDLS curve progression	
Strong evidence (Consistent $\geq 75\%$ findings in multiple ≥ 2 high quality studies)	<ul style="list-style-type: none"> • Increased Intervertebral disc degeneration • Intercrest line through L5 (rather than L4 or higher) • Apical LVT $\geq 6\text{mm}$ 	<ul style="list-style-type: none"> • Osteoporosis • Low Cobb angle $<30^\circ$ • Lumbar lordosis • Lateral osteophytes difference $\geq 5\text{mm}$ 	Limited evidence (Findings in one high quality study or consistent $>75\%$ findings in ≥ 3 low quality studies)	<ul style="list-style-type: none"> • BMI • Sagittal balance • Vertebral wedging (index) of the L4 vertebra • Degenerative spondylolisthesis • Follow-up duration • Pelvic tilt • Decreased sacral inclination • Thoracic kyphosis • Bone atrophy • Number of vertebral fractures
Moderate evidence (Findings in one high quality study and consistent $>75\%$ findings in ≥ 2 low quality studies)	<ul style="list-style-type: none"> • AVR grade II/III (Nash and Moe's) 	<ul style="list-style-type: none"> • Intercrest line through L4 • Apical LVT $<6\text{mm}$ • Direction of scoliosis • Female gender • Age 	Inconclusive evidence (Findings found in <3 low-quality studies)	<ul style="list-style-type: none"> • AVR grade I/II (Nash and Moe's) • High Cobb angle $\geq 30^\circ$ • Secondary compensatory curve at L4-S1
AVR: Apical vertebral rotation LVT: Lateral vertebral translation			Conflicting evidence ($<75\%$ of the studies reported consistent findings)	<ul style="list-style-type: none"> • Wedging of vertebra • AVR (Perdriolle and Vidal) • Apical LVT $\geq 3\text{mm}$ • Apex translation • Harrington factor (Cobb angle divided by number of vertebrae in the curve) • Apex at L2-L3 • Back pain/disability

Fig. 2 Level of evidence is shown for all associated and non-associated prognostic determinants that were identified based on Furlan et al. [34]

is related to curve progression and its role has yet to be determined (Fig. 2).

Studies of adult spinal deformity (ASD) demonstrate that positive sagittal balance is poorly tolerated and correlates with suboptimal health outcomes [48, 49]. The present review has identified limited evidence regarding the association of sagittal alignment with curve progression (Fig. 2; Table 3). As described by Aebi [7], the clinical characteristics and pathophysiology of DNDLS are different compared with other forms of ASD. This has been supported by studies which found very weak correlation between health outcomes and sagittal plane deformity, when limiting ASD to DNDLS [50, 51]. It is, therefore, most likely that a distinction between the subtypes of ASD, such as DNDLS, should be made in determining the clinical course.

Osteoporosis

Gillespy et al. and Vanderpool et al. both found osteoporosis based on plain lateral radiographs to be correlated with curve progression in DNDLS [11, 52]. More recent research found no association with curve progression when osteoporosis was measured with DEXA scans (with a smaller margin of error) [6, 18, 39, 40]. We, therefore, conclude that despite some inconsistent reports, based on the current literature and using DEXA scans for diagnosis, there is no relationship between osteoporosis and curve progression. This seems to align with other findings that de novo degenerative scoliosis is a degenerative disorder of the intervertebral disks, and not of the bones (e.g., [7, 13]).

Direction of scoliosis

Chin et al. found the left convex scoliosis to progress faster than the right convex scoliosis [38]. However, this result differs from other studies who found no correlation between the direction of scoliosis and curve progression [8, 11, 40, 41]. These contradicting findings may be explained in part by the difference between the groups. Chin et al. only looked at low magnitude DNDLS of $<30^\circ$, while contradicting studies included all patients with DNDLS of $\geq 10^\circ$ [38]. It is possible, therefore, that the direction of scoliosis may be a predictive risk factor for curve progression in the early phase of DNDLS, and not in a later phase. Unfortunately, the raw data of the contradicting studies were not available.

Clinical factors

No clinical factors (e.g., cigarette smoking, BMI, age, and gender) were identified that are related to curve progression.

Limitations

The results of this review should be interpreted cautiously. These findings are based on published data of observational studies and may be subject to various biases that may account for discrepancies found between prognostic factors and curve progression [53, 54]. Relevant (and unpublished) studies hidden in unknown databases are difficult to locate and may have been missed. Therefore, the possibility of publication bias cannot be excluded. Non-English studies were excluded in the systematic search to sufficiently assess the methodological quality. In addition, the number of prospective studies reporting on prognostic factors for DNDLS curve progression is low. There was lack of reporting of effect sizes and a large variety in definitions of DNDLS and curve progression, which made pooling of data not possible and complicated the interpretation of the reported associations. It was not possible to assess the interplay between the prognostic factors and relative contribution of each of the prognostic factors to the variance in curve progression, due to the lack of statistical methods in analyzing the prognostic value of each of the factors. In addition, these results may not be directly applicable to the individual patient. We did not study the relationship of curve progression to clinical presentation.

Conclusion

This review shows strong evidence that increased intervertebral disk degeneration, an intercrest line through L5, and lateral vertebral translation ≥ 6 mm are associated with DNDLS curve progression. Clinical risk factors (e.g.,

cigarette smoking, BMI, age, and gender) and sagittal malalignment (pelvic retroversion) and their association with curve progression have yet to be determined, and we recommend further study. We recommend obtaining an international consensus on a core set of relevant prognostic factors (clinical and radiological) and how to measure these in a standardized and valid way, so that untreated patients with DNDLS can be included in registries or long-term prospective cohort studies to help improve our understanding of the pathophysiology of curve progression in DNDLS. Although previous studies have demonstrated that progression of scoliosis may be associated with back and leg pain, more research needs to be undertaken to identify how curve progression is related to clinical course. This is crucial to establish optimal follow-up strategies and timing for therapeutic interventions for this increasing group of patients, with an increasing burden on society.

Compliance with ethical standards

Conflict of interest None.

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