Review Article

Global Spine Journal
2023, Vol. 13(2) 523–533

DOI: 10.1177/21925682221099854
journals.sagepub.com/home/gsj

Radiological Definitions of Sagittal Plane Segmental Instability in the Degenerative Lumbar Spine – A Systematic Review

Signe F. Elmose, M.D.[1], Gustav O. Andersen, B.M.[1], Leah Yacat Carreon, M.D., MSc[1], Freyr G. Sigmundsson, M.D., Ph.D.[2], and Mikkel O. Andersen, M.D.[1]

Abstract

Study Design: Systematic Review.

Objective: To collect and group definitions of segmental instability, reported in surgical studies of patients with lumbar spinal stenosis (LSS) and/or lumbar degenerative spondylolisthesis (LDS). To report the frequencies of these definitions. To report on imaging measurement thresholds for instability in patients and compare these to those reported in biomechanical studies and studies of spine healthy individuals.To report on studies that include a reliability study.

Methods: This review was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Studies eligible for inclusion were clinical and biomechanical studies on adult patients with LDS and/or LSS who underwent surgical treatment and had data on diagnostic imaging. A systematic literature search was conducted in relevant literature databases. Full text screening inclusion criteria was definition of segmental instability or any synonym. Two reviewers independently screened articles in a two-step process. Data synthesis presented by tabulate form and narrative synthesis.

Results: We included 118 studies for data extraction, 69% were surgical studies with decompression or fusion as interventions, 31% non-interventional studies. Grouping the definitions of segmental instability according similarities showed that 24% defined instability by dynamic sagittal translation, 26% dynamic translation and dynamic angulation, 8% used a narrative definition. Comparison showed that non-interventional studies with a healthy population more often had a narrative definition.

Conclusion: Despite a reputation of non-consensus, segmental instability in the degenerative lumbar spine can radiologically be defined as > 3 mm dynamic sagittal translation.

Keywords

systematic review, lumbar segmental instability, lumbar degenerative spondylolisthesis, spinal stenosis, diagnostic imaging, clinical spine surgery

Introduction

Lumbar degenerative spondylolisthesis (LDS) is the forward slippage of the proximal vertebra over a more distal vertebra caused by degeneration resulting in weakening of the surrounding structures. This leads to development of lumbar spinal stenosis (LSS), causing radicular leg pain (neurogenic claudication) with or without back pain. Surgical treatment with decompression of the neural structures have been shown to effectively relieve symptoms and improve health-related quality of life.[1] However, there are

[1] Center for Spine Surgery and Research, Spine Center of Southern Denmark, Lillebaelt Hospital, Middelfart, Denmark
[2] Department of Orthopaedic surgery, Örebro University Hospital, Örebro, Sweden

Corresponding Author:
Signe F. Elmose, Center for Spine Surgery and Research, Spine Center of Southern Denmark, Lillebaelt Hospital, Oestre Hougvej 55, Middelfart DK-5500, Denmark.
Email: Signe.Forbech.Elmose@rsyd.dk

patients who have a dynamic component such as segmental instability associated with LSS with or without LDS. With radiological signs of LDS and/or instability, the surgeon may elect to perform a fusion.[2,3] Fusion surgery is a more complex procedure, with higher cost and higher risk of complications than decompression alone.[4,5]

The term segmental instability is frequently used in the spine literature, however the concept and operational definition of segmental lumbar spine instability is controversial. The first study addressing the term dates back to 1944.[6] This and other studies investigated segmental motion using lateral flexion and extension radiographs, which is still considered the current gold standard.[6-8]

Still, studies frequently lack a definition of instability or define instability with reference to studies on healthy individuals without spinal disease or back pain.[2,9,10] Even when stated, the criteria for instability varies amongst studies. Guha et al,[9] in a literature review in 2015 presenting 24 studies on LSS to establish the incidence of iatrogenic instability, found that 10 out of 24 studies reported incidences of postoperative instability without specifying its definition, and the remaining studies defined instability as an increase in sagittal translation by varying length or percentage.

As lumbar segmental instability is used as an indication to perform fusion as a supplement to decompression alone, there needs to be an evidence-based definition of instability. In order to facilitate the process, it is necessary to describe the different definitions of instability in the sagittal plane for degenerative spondylolisthesis and the evidence supporting these definitions. Clinical associations with regards to determining treatment or outcomes of treatment is beyond the scope of this study.

Objectives

Our Objectives Were:

(1) To describe the definitions of segmental instability in the degenerative lumbar spine, in studies of patients with LSS and/or LDS, involving diagnostic imaging, and group the definitions according to measurements of segmental motion.
(2) To report the relative frequencies by which the definitions were used in the literature
(3) To report which imaging measurement thresholds for segmental motion are used, and
(4) To compare these to thresholds to the thresholds reported in radiologic, biomechanical studies and studies of healthy individuals.
(5) To report which studies, include a reliability study of their own measurements used to define instability.

Methods

Protocol and registration: Methods of the analysis, search strategy and eligibility criteria were specified in advance, documented in a protocol and submitted to the International Prospective Register of Systematic Reviews (PROSPERO) on 29. April 2020, submission ID: CRD42020182827.

Search Method

Study Design. This systematic review was conducted according to PRISMA guidelines. Checklist provided (Supplemental material file A).[11,12]

Aided by Research Librarian. The search strategy was developed with the assistance of a research librarian affiliated with the University Library of Southern Denmark, University of Southern Denmark.

Information Sources. MEDLINE (Ovid SP interface, 1948 and onwards), EMBASE (Ovid SP interface, 1947 and onwards), Cochrane Library (Wiley interface). The International Clinical Trials Registry Platform Search Portal (ICTRP, World Health Organization) and ClinicalTrials.gov (U.S. National Library of Medicine) were searched for ongoing or recently completed trials. PROSPERO (International Prospective Register of Systematic Reviews, National Institute of Health Research) was searched for ongoing or recently completed systematic reviews.

See Supplemental file B for proposed strategy for MEDLINE. After adaptation, similar structured search strategies were used with syntax and subject headings appropriate for each database.

Searching other Resources. Reference lists of all primary studies identified were reviewed and added as appropriate. A search through the program/abstract books of relevant national and international societies of spine surgery was also performed.

Date of Search. The initial search was conducted in June 2020 and updated in March 2021.

Language. English, Danish, Norwegian, Swedish language articles were included.

Search terms. Literature search strategies were developed by block building, using medical subject headings (MeSH) and exploded when necessary. Floating subheadings were used appropriately. Free text and keyword search with relevant synonyms and antonyms was used: spondylolisthesis; anterolisthesis; slipped vertebra; vertebral sliding; spinal stenosis; lumbar spine segmental instability; lumbar segmental instability; lumbar spine instability; lumbar segmental translation; sagittal slip; segment motion; stability; Magnetic resonance imaging; MRI; radiography; roentgenogram; roentgenograph; arthrography; myelography; tomography, x-ray; CT-scan; computed tomography; radiologic.

No methodological filters were applied to the electronic searches.

Screening Process

After the search was run, the references were exported to EndNote X9[13] and to COVIDENCE software.[14] Duplicates were removed. Title and abstract screening of all records identified by the search were conducted independently by 2 researchers. To ensure consistency across reviewers, we conducted calibration exercises before starting the screening process. Full text of all potentially relevant articles was retrieved and screened for final inclusion independently by 2 researchers. Any disagreement was resolved by discussion with a tertiary reviewer functioning as referee.

Eligibility Criteria. Inclusion criteria were published studies (full text, abstracts and E-publications ahead of print) including any imaging of the human lumbar spine evaluating spinal instability of a surgical segment in adults with LSS or LDS. Studies that reported on "normal" values in a spine healthy non-clinical population (in the following referred to as "healthy") were also included. Studies evaluating intra-operative instability without the use of any imaging were excluded.

Accepted synonyms of instability were dynamic spondylolisthesis, slippage, slip, translation, subluxation; segmental or segment motion and abnormal movement. Studies investigating the antonym "stability" as a general term were also included.

Since studies might not state instability as part of the study purpose, abstract or title, MRI and radiographic characteristics of segmental instability were added as inclusion criteria. These include facet joint angle; facet effusion/gap/fluid/vacuum; intradiscal vacuum; disc height (in combination with any of the other terms); spondylolisthesis; slippage; slip; stability; vertebral motion, translation, movement or slip; slip degree or difference; segmental angulation; segmental lordosis or kyphosis; disc angle; range of motion; facet or ganglion cysts if instability was mentioned.

If a study was published as a both conference abstract and full text article, only the full text article was included. If multiple reports from same study using the same definition and the same cohort met criteria only 1 article was included

During the screening process it became clear that our eligibility criteria had to be adjusted as we encountered mixed populations and had to specify that a minimum of 50% had to be degenerative LSS or LDS. We also specified that adjacent segment instability was not the aim of our study.

We contacted the corresponding authors if there was missing information regarding the study population with a maximum of 3 attempts. If the author did not reply, the study was excluded.

Data Extraction And Management

One reviewer extracted data, and the process was repeated for verification. We performed calibration exercises before commencement. Any disagreement resolved by discussion with a second reviewer as referee. A pre-formatted Microsoft Excel (Microsoft Office, Redmond, WA) spreadsheet created to record extracted data. However, as studies were being reviewed, the spreadsheet was revised in an iterative process.

Data Items. Information extracted from each study were author, year of publication, study design, sample size, inclusion criteria, and intervention.

The outcome of interest was the definition of segmental instability of the lumbar spine, presented as a numeric measurement or as a narrative. Functional imaging measurements (translation, slip degree, segmental angulation, segmental range of motion) and threshold values were also collected if available. In addition, if the studies included an evaluation of the inter-rater or intra-rater reliability of the imaging measurements these were also collected.

Table 1 lists the imaging measurement parameters and a description of interpretation.

(References for Table 1: slip degree[10,15,16]; angulation[15,17]; difference in slip percentage[17]; dynamic angulation[15,17,18]; rotatory hypermobility[19]; segmental kyphosis[20]).

The method of measurement was noted if presented. The projection plane of the digital image was noted if other than sagittal.

Dynamic or functional radiographs were interpreted to be flexion-extension radiographs. Dynamic measurements were interpreted as the difference from flexion to extension unless otherwise stated. If 2 different modalities where used to asses instability such as standing radiographs and supine MRI, it was categorized as dynamic imaging.

Assessment of Methodological Quality. Since data extracted for the objectives of this review was not related to the study design no study quality assessment was conducted.

Synthesis Methods. Data synthesis presented by tabulate form, presenting definitions group according to radiographic or narrative similarities. Furthermore, a systematic narrative synthesis of data.

Results

Study Selection

We screened 5124 abstracts and 619 full text articles (Figure 1, adapted from Page et al[21]) with 118 studies included for data extraction. We conducted 4 pilot screenings. We contacted 7 authors regarding study populations, 5 responded.

Study Characteristics

A summary of the study characteristics is outlined in Table 2, for more specific information and references see Supplemental file C. Mean number of patients in each study was 85 ranging from 1 – 295.The mean age in the intervention studies was 64 years (combined age range 20 - 89 years) and in the non-interventional studies 60 years (combined age range 19 - 100 years).

Study populations consisted of LSS, LDS, lumbar degenerative instability patients and/or healthy individuals with

Table 1. Listing Imaging Measurement Parameters and a Description of How These will be Interpreted and Grouped.

Measurement parameter	Alternative wording	Description
Translation	Slip	Motion in the sagittal plane if not explicitly stated
Slip degree	- Degree of slippage - Percentage of slip	The ratio of the length of the amount of slip to the width of superior endplate of the distal vertebral body
Angulation	Segmental intervertebral angulation	The angle formed by the intersection of the lines drawn as a continuation of the vertebral endplates above and below the disc in the sagittal plane
Dynamic translation	Dynamic slip	Difference in translation between flexion and extension.
Difference in slip percentage	Difference in slip degree	Dynamic measurement of the slip degree or percentage difference between flexion and extension
Dynamic angulation	Sagittal rotation angle	The difference of intervertebral angles between flexion and extension
Range of motion (ROM)	Rotatory hypermobility	Angle formed by lines drawn through the inferior endplate of the upper vertebra in flexion and extension. ROM was interpreted as dynamic angulation and grouped accordingly
Segmental kyphosis	Kyphotic angle in flexion	Posterior disc height higher than anterior disc height. On flexion radiographs determined by measuring the intervertebral angle on flexion radiograph, positive angle equals kyphosis.

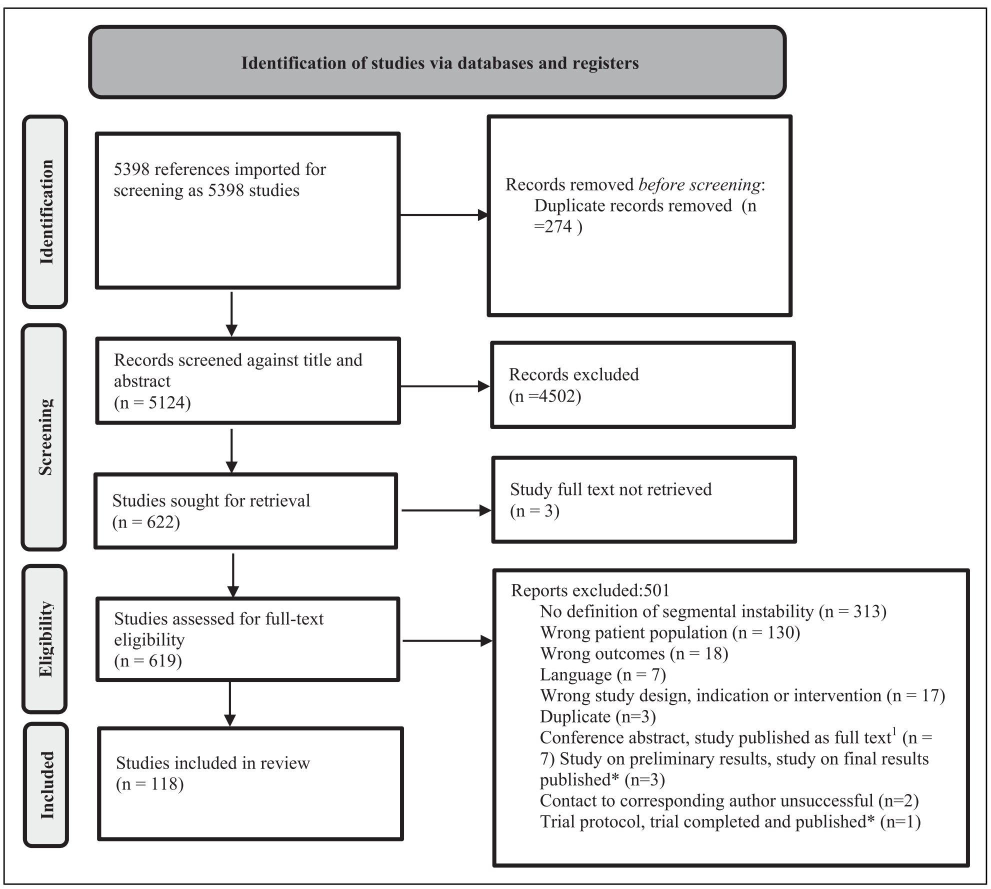

Figure 1. Preferred reporting items for systematic reviews and meta-analysis Flow Chart illustrating the screening process and rationale for exclusion. [1,*]Study retrieved and assed for full-text eligibility.

no history of back pain. Mixed samples, patients with disc herniation, spondylolytic or isthmic spondylolisthesis, degenerative scoliosis, low back pain or other degenerative spine disease patients, constituted <50% of the total population.

The studies investigating a surgical intervention reported segmental instability as an outcome in 82%. The majority of studies (84%) reported using a dynamic assessment of instability (Table 3).

Table 2. Summarized Characteristics with Frequency and Percentage of Studies Included.

	N	Percentage[a]
Study design		
Cohort	76	64
Cross-sectional	22	19
Case series/Case reports	4	3
Case-control	4	3
Randomized clinical trials	3	3
Reviews	6	5
Protocol	3	3
Intervention		
Surgical	82	69
Fusion[b]	40	34
Decompression	34	29
Dynamic stabilization	7	6
NR	1	1
Non interventional	36	31
Radiologic study	30	25
Review	6	5
Population		
LDS	42	36
LSS	22	19
Mixed[c]	38	32
Spinal instability +/− LDS/LSS	7	6
Healthy individuals[d]	4	3
Healthy + mixed	5	4

Abbreviations: N, number; NR, not reported; LSS, Lumbar spinal stenosis; LDS, lumbar degenerative spondylolisthesis.
[a]Percentage: N/118 studies *100.
[b]Fusion = +/−decompression.
[c]Mixed: LDS/LSS +/− other degenerative spinal disease, disc herniation, isthmic spondylolisthesis or low back pain.
[d]Healthy = no history of spinal disease.

Table 3. Diagnostic Imaging Modalities Described to Asses Instability. Diagnostic Imaging Divided Into Dynamic Assessment and Static Assessment. Dynamic Is Interpreted as Comparing to different Positions

	N	Percentage[a]
Dynamic assessment		
Upright flex-ex x-ray	79	67
Upright neutral + supine x-ray/CT/MRI	12	10
Recumbent lateral flex-ex	6	5
CT/MRI/NR	5	4
Static assessment		
Upright neutral x-ray	6	5
Supine MRI/CT	4	3
Recumbent lateral x-ray	2	2
NA/NR	4	3
Total	118	100

[a]Percentage: N/118*100.
N: number; Upright: standing upright position; Flex-ex: flexion and extension; x-ray: radiograph; NA: not applicable; NR: not reported; /: or; +: and.

Synthesis of Results

Objective i+ii. We grouped the definitions based on radiographic measurement or narrative similarities (Table 4).

The group of studies defining instability narratively used words or phrases such as "increased mobility and abnormal spinal motion", "excessive movement", "movement or motion beyond normal constraints", "abnormal response to applied loads", "loss of active stiffness". Studies stating the presence of spondylolisthesis as definition of instability were grouped under "spondylolisthesis".

See Supplemental file D for the full overview of the groups. We were not able to group 17 out of 118 definitions in a meaningful way. These definitions included various parameters in the definition of instability with up to 6 different parameters, both static and dynamic (Supplemental file D).

Objective iii:. We broke down the definitions of the 118 studies into radiographic parameters. Table 5 depicts the most frequent (>6 studies include the parameter in the definition) and show the range and mode of reported thresholds, also shown are the number of studies to report a definition that includes the parameter. Boden and Wiesel investigated normal range of motion of the lumbar vertebral and concluded that normal lumbar vertebral levels should have less than 3.0 mm of dynamic sagittal translation or slip percentage difference <8%.[8] Table 5 shows the number of studies to report a threshold value above the threshold reported by Boden and Wiesel.

Objective iv. The mode of thresholds was similar for each parameter when comparing interventional and non-interventional and healthy population vs patient population (Table 6).

However, the non-interventional and studies with a healthy population reported a narrative definition more often than the interventional studies and studies with a patient population.

Objective v:. Fourteen studies included a reliability study of their measurements of parameters used to define instability. The studies presented good to excellent reliability for their measurements. Two studies only presented intra-rater reliability data. Eleven studies where non-interventional radiologic studies.

Discussion

What defines segmental instability of the spine has been a clinical and scientific question for almost a century. Defining segmental instability has an impact on surgical decision-making, as the presence of instability may require the addition of a fusion procedure along with the decompression.[2,22,23] The results of this study show the definition of segmental instability vary in patients with LSS and/or LDS.[2,9]

Table 4. Definitions of segmental Instability. The Frequency and Percentage Definitions of Segmental Instability When Grouping Them According to Radiographic and Narrative Similarities.

Definition of Instability	N	Percentage[a]
Dynamic sagittal translation	28	24
Dynamic translation and dynamic angulation	31	26
Dynamic translation, dynamic angulation and slip percentage difference	7	6
Dynamic translation and slip percentage difference	3	3
Static translation	5	4
Dynamic angulation and slip percentage difference	3	3
Slip percentage difference	7	6
Facet effusion	3	3
Narrative	9	8
Spondylolisthesis	5	4
Could not be grouped	17	14
Total	118	100

N: number.
[a]Percentage: N/118 studies *100.

Table 5. The Range of Reported Thresholds From Most Frequent Reported Parameters. The Range and Mode of Threshold Values From the Most Frequent Parameters Used to Define Instability, and the Number of Studies to Report the Parameter in the Definition of Instability.

	Dynamic translation (mm)	Dynamic angulation (°)	Slip percentage difference (%)	Kyphotic angle[a] (°)	Static translation[b] (mm)	Slip percentage (%)
Range	2-5	2-25	3-15	5-9	2-4.5	8-25
Mode	3	10	8	5	2;3;4.5	8
N	77	47	24	10	8	9
Boden normal values[c]	<3	—	<8	—	—	—
N> Boden[d]	64	—	19	—	—	—

N: number of studies.
[a]Kyphotic angle: Degree of posterior opening on lateral projection flexion radiograph.
[b]Static translation: The studies reported by equal frequency the thresholds 2, 3 and 4.5 mm.
[c]Boden normal values: the threshold for motion at normal lumbar vertebral levels reported by Boden and Wiesel 1990.[8]
[d]N> Boden: number of studies to report a threshold for instability above the normal values.

Table 6. Comparison of thresholds. Comparison of Radiographic Parameter Thresholds Between Interventional and Non-Interventional Studies and Studies with a Patient vs Healthy Population. Based Upon the Most Frequent used Radiographic Parameters. Also Shown a Comparison of How Narrative Definitions was Distributed.

	Dynamic translation			Dynamic angulation			Slip percentage difference			Narrative	
	Threshold mode (mm)	N	%	Threshold mode (°)	N	%	Threshold mode (%)	N	%	N	%
Interventional (n = 82)	3	58	71	10	34	41	8 and 15	14	17	4	5
Non-interventional (n = 30)	3	14	47	10	9	30	8	9	30	9	30
Healthy[a] (n = 9)	3	2	22	—	—	—	8	1	11	6	67
Patients[b] (n = 109)	3	75	69	10	47	43	8	23	21	8	7

N and n: number of studies %: percentage = N/n
[a]Healthy: studies with a population of healthy participants or healthy and patients.
[b]Patients: studies with a population of LSS, LDS or mixed with other patient groups

With this review, we systematically searched the literature for studies that present a definition of segmental instability in the degenerative lumbar spine. We focused on a population of LSS and LDS patients and included studies on surgical intervention or non-interventional radiologic studies of this population. To our knowledge this is the largest review of literature concerning the concept of segmental instability.

There is a general agreement that instability is a dynamic concept and should be based on dynamic radiographic parameters. The most frequently used radiographic modalities were lateral flexion and extension radiographs and an upright lateral radiograph compared to a supine image, either an MRI or a CT Scan. In 1944, Knutsson[6] was the first to describe the functional assessment of instability using the upright flexion and extension radiograph. However, this standard protocol has been challenged, as patients may have limited motion during upright flexion-extension due to increased paraspinal muscle tension, presence of low back pain, patient compliance and concomitant degenerative changes in other spinal segments which might influence motion.[24,25] In addition, it is debated if the flexion-extension radiographs should be taken with the patient upright or laying on their side.[16,26,27]

Studies have shown that other radiographic protocols might be more sensitive or accurate than standing flexion and extension radiographs.[25,26,28-30] Recently, Liu et al[25] compared flexion-extension radiographs to an upright lateral radiograph and supine MRI (upright-supine method) and showed that the slip percentage difference was significantly higher in the upright-supine method than that observed by the flexion-extension method. Other studies support these findings regarding dynamic changes in alignment from upright to supine images.[24,26,29] The debate about the most appropriate radiological protocol for assessing segmental instability therefore continues. Furthermore, whether the difference found between upright-supine and flexion-extension imaging is clinically relevant has been questioned by Viswanathan et al[30] They found no difference in clinical outcomes between patients selected for transforaminal lumbar interbody fusion based on flexion-extension or upright-supine imaging criteria.[30]

Despite there being some lack of consensus, we have found that the definitions of instability in the literature have similarities. We were able to identify similarities and group the definitions according to certain parameters, as shown in Table 4. Our results show that the majority of studies define instability as abnormal alignment (sagittal translation or slip degree) and/or excessive mobility (slip degree difference, angulation or ROM).[8,17,18,31] Furthermore, studies defining segmental instability using radiographic parameters, most frequently include dynamic translation and dynamic angulation and/or slip degree difference.

By assessing these parameters individually, we found, that the most frequent were dynamic translation of 3 mm, dynamic angulation 10° and slip degree difference 8% (Table 5). Studies stating a threshold of 3 mm dynamic translation often refer to a study by Boden and Wiesel from 1990.[8] Boden and Wiesel conducted a study to define normal lumbosacral segmental motion in 40 healthy male volunteers on upright lateral flexion-extension radiographs. They reported that normal individuals can show dynamic translation up to 3 mm in sagittal plane with a significant variation between normal individuals. They concluded that normal lumbar vertebral levels should have less than 3 mm dynamic sagittal translation or <8% of vertebral body width. This exact definition was not uniformly used in the included studies included in the present review. Most often, only the 3 mm threshold was used. It seems reasonable to suggest ≥ 3 mm as the threshold for dynamic translation, since the majority of studies (65%) include dynamic translation in their definition and >80% of these stated a threshold above the "normal" value as suggested by Boden and Wiesel (Table 5).

The most frequent threshold for dynamic angulation or ROM reported was 10° (Table 5). However, the origin of this threshold is unclear. Following references for the threshold 10° angulation lead to a radiographic study by Penning and Blickman from 1980[32] on patients with isthmic spondylolisthesis. They reported a wide range of intervertebral angular mobility and that >10° intervertebral mobility compared to the adjacent level could be a sign of instability. However, the studies included in the present review stated the parameter merely as dynamic angulation of >10°. Another frequently used reference was a checklist by White and Panjabi from 1990.[18] However, White and Panjabi stated angular motion thresholds according to lumbar vertebral level ranging from 15°- 25°. In addition, the checklist applies to instability in general and not exclusively to degenerative instability. White and Panjabi[18] based their checklist upon evidence obtained by experimental biomechanical experiments such as a study by Posner et al from 1982.[17] The study by Posner et al[17] was a biomechanical cadaver study investigating lumbar functional spinal units under conditions that simulate maximum physiologic load to determine the upper limits of normal motion and the tolerance when vertebral components were destroyed. Posner et al also presented a checklist to evaluate lumbar instability. The checklist was designed for traumatic injuries and may not necessarily be applicable for degenerative changes. Posner et al.[17]investigated angulation and showed a variation in angulation in intact cadaver spine specimens. In vivo studies have confirmed these findings and some studies have questioned the relevance of angulation when assessing degenerative instability.[8,24,29,33] Different methods of measuring angulation also make it difficult to compare results across studies. Chen et al suggested poor clinical significance of this parameter since degenerative changes of the intervertebral space and facet joints might hinder angular mobility.[24] Chen et al showed that a kyphotic segment (kyphotic slip angle) in LDS should be regarded instable, however, they did not include it in their definition.[24] Biomechanically, a kyphotic segment in the lumbar spine could be a sign of loss of anterior column support. In non-degenerated discs the anterior support is applied by tensile strain resulting from turgor pressure of the disc on the inner fibrous ring and anterior longitudinal ligament. However, degenerative changes to the fibers decreases the capability to withstand tensile stress forces. A kyphotic disc angle in a lumbar segment could indicate reduced tensile strain and inability to withstand anterior shear forces leading to segmental translation.[24] Posner et al [17]was 1 of the first to state a threshold for kyphotic angle in flexion. As mentioned, 8% of the studies in the present review included a kyphotic angle or posterior opening in flexion in their definition of instability.[22,28,34-41]

Posner et al[17] also investigated slip percentage difference and reported a threshold of >8% in their checklist. This was later confirmed by Boden and Wiesel.[8] In this study, around 80% of the studies that include this parameter had a threshold equal to or above the 8%. Applying slip percentage to evaluate translation reduces risk of errors due to magnification and may be more suitable for comparison between studies.

Compared to interventional studies, non-interventional studies more often gave a narrative definition of segmental instability rather than a radiographic threshold. This might be due to the fact that most interventional studies use instability as an outcome and therefore need a practical operational definition. Whereas the purpose of the majority of the non-interventional studies investigate the concept of instability and therefore define it in general biomechanical terms. The most frequent parameters and thresholds reported within the different categories were similar.

Reliability of the various radiographic measures were not widely reported and used different parameters to evaluate interrater reliability. This made it difficult to compare reliability data across studies. However, in general the few studies to report on reliability showed good inter-rater agreement.

Even though most studies describe instability as a dynamic concept, some studies defined instability as the presence of spondylolisthesis, Table 4. Studies such as Aggarwal and Even et al[42] show that it is necessary to distinguish between static and dynamic LDS. Biomechanically it makes sense to divide LDS into static and dynamic. However, some studies present dynamic instability which indicates that instability can be static.[38,43-47]

A few studies in this review presents a definition including facet effusion and facet angle as parameters.[22,36,48,49] The studies are published within the last decade. Signs of instability on MRI are subject of investigation and results indicate that facet effusion sign, sagittal facet angles, disc height and facet tropism might be linked to instability.[35] However, predictors of instability are beyond the scope of this review.

Limitations: This systematic review has limitations. A broad perspective was necessary when constructing a search string sensitive enough to capture studies that potentially defined instability, and also to capture studies that has instability as a part of the objective and keywords, and simultaneously avoid introducing bias to the search. We are aware that this strategy will yield a low search specificity. However, to increase the specificity of the search, we included the population and diagnostic imaging in the search string. We also increased the specificity by the two-step screening process by independent researchers. Another potential limitation by the broad perspective is the different study designs included. This makes statistical comparisons across studies difficult. However, we accounted for this perspective in our data synthesis plan. We included studies with mixed populations which is expressed in the wide age range of the included studies. Not all studies have a population of exclusively degenerative LSS or LDS, and we included studies on healthy individuals. We still believe the studies are representative of the degenerative population as we did not include studies with <50% degenerative patients.

We did not have 2 blinded reviewers to conduct data extraction. The verifier could potentially already be influenced by the result the first reviewer found. However, data extraction was conducted by a reviewer on 2 occasions with a minimum of 2 weeks apart. An assessment of the risk of bias is an important part of any systematic review.[50] However, our objectives are not influenced by study design, and a critical appraisal of the methodology quality are not relevant. We argue, that assessing risk of bias and excluding studies on that basis might induce selection bias to our results. It could seem relevant to address reporting bias, since we anticipate that not all studies will give a definition of instability. However, we have chosen to focus on describing the existing definitions. An investigation of the frequency of reporting a definition of instability could be an objective for a future review. Future research should focus on determining a validated definition of segmental instability in the degenerative spine.

Conclusion

We conducted a systematic review of the radiological definition of segmental sagittal plane instability. We included studies on the degenerative lumbar spine, including studies of patients with LSS and/or LDS, with diagnostic imaging. By grouping the definitions according to measurements of segmental motion and summarizing the most frequent parameters and their measurement thresholds we have found, that despite having a reputation of non-consensus, the concept of segmental degenerative instability in the sagittal plane can be radiologically summed up to $\geq$ 3 mm dynamic sagittal translation and >10° dynamic angulation. Angulation have various definitions and protocols for measurements. Furthermore, thresholds based upon degenerative angulation is sparse and with large variation, making it less suitable for a recommendation. Based upon our findings, we recommend a radiological definition of segmental instability of $\geq$ 3 mm dynamic sagittal translation. Future studies should focus on determining the validity of MRI signs of segmental instability to decrease unnecessary x-ray exposure.

Appendix

List of abbreviations

PRISMA-P	Preferred Reporting Items for Systematic Reviews and Meta-Analysis protocols
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROSPERO	the International Prospective Register of Systematic Reviews
LDS	lumbar degenerative spondylolisthesis
LSS	lumbar spinal stenosis
MeSH	medical subject headings
ICTRP	International Clinical Trials Registry Platform Search Portal
ROM	Range Of Motion
MRI	Magnetic Resonance Imaging
	CT scan: Computed Tomography Scan

Acknowledgments

The authors acknowledge the great help form research librarian Mette Brandt Eriksen, PhD, University Library of Southern Denmark, University of Southern Denmark (SDU), for her contribution and support in developing the search strategy.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: TICMJE forms applied

Trail Registration

International Prospective Register of Systematic Reviews (PROSPERO): CRD42020182827. Last update December 2020

Data Statement

Suitable research data provided as supplementary files.

ORCID iDs

Signe F. Elmose https://orcid.org/0000-0003-1522-072X
Gustav O. Andersen https://orcid.org/0000-0002-7598-7538
Leah Yacat Carreon https://orcid.org/0000-0002-7685-9036
Freyr G. Sigmundsson https://orcid.org/0000-0002-7376-4664
Mikkel O. Andersen https://orcid.org/0000-0001-8478-8218

Supplemental Material

Supplemental material for this article is available online.

References

1. Paulsen RT, Bouknaitir JB, Fruensgaard S, Carreron L, Andersen M. Patient are satisfied one year after decompression surgery for lumbar spinal stenosis. *Danish medical journal* 2016;63(11):A5299.
2. Simmonds AM, Rampersaud YR, Dvorak MF, Dea N, Melnyk AD, Fisher CG. Defining the inherent stability of degenerative spondylolisthesis: a systematic review. J Neurosurg Spine 2015; 23(2):178-189. doi:10.3171/2014.11.spine1426
3. Ghogawala Z, Dziura J, Butler WE, Dai FNSN . Laminectomy plus fusion versus laminectomy alone for lumbar spondylolisthesis. N Engl J Med 2016;374(15):1424-1434. doi:10.1056/NEJMoa1508788
4. Ulrich NH, Burgstaller JM, Pichierri G, et al. Decompression surgery alone versus decompression plus fusion in symptomatic lumbar spinal stenosis: A swiss prospective multicenter cohort study with 3 years of follow-up. *Spine (Phila Pa 1976)* 2017;42(18):E1077-E1086. doi:10.1097/BRS.0000000000002068
5. Försth P, Ólafsson G, Carlsson T, et al. A randomized, controlled trial of fusion surgery for lumbar spinal stenosis. *N Engl J Med*, 2016;374(15):1413-1423.
6. Knutsson F The instability associated with disk degeneration in the lumbar spine. *Acta Radiologica*. 1944;25(5-6):593-609. doi:10.3109/00016924409136488
7. Aho A, Tahti E. Significance of functional radiography of the lumbar spine in forward and backward flexion. *Ann Chir Gynaecol Fenn*. 1957;46(3):336-350.
8. Boden SD, Wiesel SW. Lumbosacral segmental motion in normal individuals: Have we been measuring instability properly? *Spine*. 1990;15(6):571-576.
9. Guha D, Heary RF, Shamji MF. Iatrogenic spondylolisthesis following laminectomy for degenerative lumbar stenosis: systematic review and current concepts. *Neurosurg Focus*. 2015; 39(4):E9. doi:10.3171/2015.7.FOCUS15259
10. Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. J Bone Joint Surg Am 1990;72(3):403-408.
11. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol* 2009;62(10):1006-1012. doi:10.1016/j.jclinepi.2009.06.005
12. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PCJPA. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. J Clin Epidemiol 2009;62(10): e1-e34. doi:10.1016/j.jclinepi.2009.06.006

13. EndNote. *Version EndNote X9*. London, UK: Clarivate Analytics; 2013.
14. COVIDENCE. *Veritas Health Innovation*; 2019. Covidence systematic review software. *Veritas Health Innovation, Melbourne*; Australia. Available at www.covidence.org.
15. Dupuis PR, Yong-Hing K, Cassidy JD, Kirkaldy-Willis WH. Radiologic diagnosis of degenerative lumbar spinal instability. *Spine* 1985;10(3):262-276.
16. Wood KB, Popp CA, Transfeldt EE, Geissele AE. Radiographic evaluation of instability in spondylolisthesis. *Spine*. 1994;19(15):1697-1703. doi:10.1097/00007632-199408000-00008.
17. Posner I, White AA 3rd, Edwards WT, Hayes WC. A biomechanical analysis of the clinical stability of the lumbar and lumbosacral spine. *Spine (Phila Pa 1976)*. 1982;7(4):374-389. doi:10.1097/00007632-198207000-00008.
18. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, PA: Lippincott; 1990.
19. Aota Y, Kumano K, Hirabayashi S. Postfusion instability at the adjacent segments after rigid pedicle screw fixation for degenerative lumbar spinal disorders. J Spinal Disord 1995;8(6):464-473.
20. Luk KDK, Chow DHK, Holmes A. Vertical instability in spondylolisthesis: A traction radiographic assessment technique and the principle of management. *Spine*. 2003;28(8):819-827. doi:10.1097/00007632-200304150-00016.
21. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Bmj* 2021;372:n71. doi:10.1136/bmj.n71.
22. Maher A. Understanding surgeon decision-making and current surgical practice regarding the DSIC scheme and DLS treatment: a CSORN study. Conference Abstract. Spine Journal 2019;19 (9 suppl ment):S14-S15. doi:10.1016/j.spinee.2019.05.042.
23. Ghogawala Z, Benzel EC, Amin-Hanjani S, Barker FGJFSN. Prospective outcomes evaluation after decompression with or without instrumented fusion for lumbar stenosis and degenerative Grade I spondylolisthesis. Research Support, Non-U.S. Gov't. Journal of Neurosurgery Spine 2004;1(3):267-272.
24. Chen X, Zhou QS, Xu L, et al. Does kyphotic configuration on upright lateral radiograph correlate with instability in patients with degenerative lumbar spondylolisthesis? *Clin Neurol Neurosurg* 2018;173:96-100. doi:10.1016/j.clineuro.2018.07.020.
25. Liu N, Wood KB, Schwab JH, Cha TDFXRD . Utility of flexion-extension radiographs in lumbar spondylolisthesis. *Spine*. 2015;40(16):E929-E935. doi:10.1097/BRS.0000000000000941.
26. Tarpada SP, Cho W, Chen F, Amorosa LF. Utility of supine lateral radiographs for assessment of lumbar segmental instability in degenerative lumbar spondylolisthesis. *Spine* 2018;43(18):1275-1280. doi:10.1097/BRS.0000000000002604.
27. Luk KD, Chow DH, Holmes A. Vertical instability in spondylolisthesis: a traction radiographic assessment technique and the principle of management. *Spine*. 2003;28(8):819-827.
28. Morita T, Yoshimoto M, Terashima Y, et al. Do we have adequate flexion-extension radiographs for evaluating instability in patients with lumbar spondylolisthesis? *Spine*. 2020;45(1):48-54. doi:10.1097/BRS.0000000000003203.
29. Cabraja M, Mohamed E, Koeppen D, Kroppenstedt S. The analysis of segmental mobility with different lumbar radiographs in symptomatic patients with a spondylolisthesis. Comparative Study. Europ Spine J 2012;21(2):256-261. doi:10.1007/s00586-011-1870-y.
30. Viswanathan VK, Hatef J, Aghili-Mehrizi S, Minnema AJ, Farhadi HF. Comparative utility of dynamic and static imaging in the management of lumbar spondylolisthesis. Comparative Study Evaluation Study. *World Neurosurg* 2018;117:e507-e513. doi:10.1016/j.wneu.2018.06.066.
31. Frymoyer JW, Pope MH, Wilder DG. Segmental Instability. In: JN Weinstein, SW Wiesel, eds *The Lumbar Spine*. The International Society for the Study of the Lumbar Spine; 1990: 612-636:chap 10.
32. Penning L, Blickman JR. Instability in lumbar spondylolisthesis: a radiologic study of several concepts. AJR Am J Roentgenol. 1980;134(2):293-301. doi:10.2214/ajr.134.2.293.
33. Hayes MA, Howard TC, Gruel CR, Kopta JA. Roentgenographic evaluation of lumbar spine flexion-extension in asymptomatic individuals. *Spine*. 1989;14(3):327-331.
34. Herno A, Airaksinen O, Saari T, Pitkanen M, Manninen H, Suomalainen O. Computed tomography findings 4 years after surgical management of lumbar spinal stenosis: No correlation with clinical outcome. *Spine*. 1999;24(21):2234-2239. doi:10.1097/00007632-199911010-00011.
35. Tamai K, Kato M, Konishi S, Matsumura A, Hayashi K, Nakamura H. Facet effusion without radiographic instability has no effect on the outcome of minimally invasive decompression surgery. *Global Spine J*. 2017;7(1):21-27. doi:10.1055/s-0036-1583173.
36. Kulkarni AG, Kunder TS, Dutta S. Degenerative spondylolisthesis: When to fuse and when not to? A new scoring system. Clin Spine Surg 33, E391-E400, 2020;doi:10.1097/BSD.0000000000000970.
37. Matsumoto T, Okuda S, Nagamoto Y, Sugiura T, Takahashi Y, Iwasaki M. Effects of concomitant decompression adjacent to a posterior lumbar interbody fusion segment on clinical and radiologic outcomes: Comparative analysis 5 years after surgery. *Global Spine J*. 2019;9(5):505-511. doi:10.1177/2192568218803324.
38. Minamide A, Yoshida M, Simpson AK, et al. Minimally invasive spinal decompression for degenerative lumbar spondylolisthesis and stenosis maintains stability and may avoid the need for fusion. *Clinical Trial. Bone & Joint J*. 2018;100-B(4):499-506. doi:10.1302/0301-620X.100B4.BJJ-2017-0917.R1.
39. Yone K, Sakou T, Kawauchi Y, Yamaguchi M, Yanase M. Indication of fusion for lumbar spinal stenosis in elderly patients and its significance. *Case Reports. Spine*. 1996;21(2):242-248.
40. Hashimoto T, Oha F, Shigenobu K, Kanayama MMY . Mid-term clinical results of Graf stabilization for lumbar degenerative

pathologies: A minimum 2-year follow-up. *Spine J*. 2001;1(4): 283-289. doi:10.1016/S1529-9430%2801%2900028-6.
41. Kanayama M, Hashimoto T, Shigenobu K, Togawa D, Oha F. A minimum 10-year follow-up of posterior dynamic stabilization using Graf artificial ligament. *Comparative Study.* Spine. 2007; 32(18):1992-1997; discussion 1997.
42. Even JL, Chen AF, Lee JY. Imaging characteristics of "dynamic" versus "static" spondylolisthesis: Analysis using magnetic resonance imaging and flexion/extension films. Spine J 2014;14(9):1965-1969. doi:10.1016/j.spinee.2013.11.057.
43. Slikker W, Orias AAE, Shiffle GD, et al. Image-based markers predict dynamic instability in lumbar degenerative spondylolisthesis. Neurospine 2020;17(1):221-227. doi:10.14245/ns.1938440.220.
44. Snoddy MC, Sielatycki JA, Sivaganesan A, Engstrom SM, McGirt MJ, Devin CJ. Can facet joint fluid on MRI and dynamic instability be a predictor of improvement in back pain following lumbar fusion for degenerative spondylolisthesis? Eur Spine J 2016;25(8):2408-2415. doi:10.1007/s00586-016-4525-1.
45. Chen X, Zhou QS, Xu L, et al. Does kyphotic configuration on upright lateral radiograph correlate with instability in patients with degenerative lumbar spondylolisthesis? *Clin Neurol Neurosurg*. 2018;173:96-100. doi:10.1016/j.clineuro.2018.07.020.
46. Dombrowski ME, Rynearson B, LeVasseur C, et al. ISSLS prize in bioengineering science 2018: Dynamic imaging of degenerative spondylolisthesis reveals mid-range dynamic lumbar instability not evident on static clinical radiographs. Research Support, N.I.H., Extramural Research Support Non-U.S. Gov't. *Eur Spine J*. 2018;27(4):752-762. doi:10.1007/s00586-018-5489-0.
47. Sriphirom P, Siramanakul C, Chaipanha P, Saepoo C. Clinical outcomes of interlaminar percutaneous endoscopic decompression for degenerative lumbar spondylolisthesis with spinal stenosis. *Brain Sci*. 2021;11(1):1-8. doi:10.3390/brainsci11010083.
48. Lattig F, Fekete TF, Kleinstuck FS, Porchet F, Jeszenszky D, Mannion AF. Lumbar facet joint effusion on MRI as a sign of unstable degenerative Spondylolisthesis. *J Spinal Disord Tech*. 2015;28(3):95-100. doi:10.1097/BSD.0b013e318269c261.
49. Francaviglia N, Costantino G, Villa A, Iacopino DGMP. Preliminary experience with a novel system of facet fixation to treat patients with lumbar degenerative disease. A new perspective in minimally invasive spine surgery? *J of Neurol Surg*. 2018;79(4):296-301. doi:10.1055/s-0037-1607196.
50. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4:1. doi:10.1186/2046-4053-4-1.