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REVIEW ARTICLE

Vertebral endplate defects: nomenclature, classification and measurement methods: a scoping review

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Abstract

Purpose To summarize the scope of nomenclature and measurement methods used to document endplate defects in the health sciences literature.

Methods The scoping review followed the York framework and was reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews. The databases of PubMed, Scopus, Embase and CINAHL were searched using key terms. Screening and selection were conducted by two independent reviewers. A standardized, pilot-tested form was used for extracting data, which were analyzed descriptively.

Results The review included 211 studies, originating from 29 countries, with the USA (18.8%) and China (12.26%) as leading contributors. Thirty-four different terms for structural endplate defects were reported, but were never defined in most studies (65%). Of the 34 different terms used, some appeared to represent the same phenomenon, while the same terms were occasionally defined differently between studies. Schmorl's nodes were most commonly investigated ($n = 99$ studies) and defined similarly across studies, with the main difference relating to whether the indentation (node) was required to have a sclerotic margin. There were also similarities in definitions for endplate sclerosis. However, there was great variability in the definitions of other terms, such as lesions, irregularities, abnormalities, erosions and changes.

Conclusion With the possible exception of Schmorl's nodes, we lack a common language for effectively communicating structural endplate findings. This review provides a foundation and impetus for standardizing terminology and core measures to improve communication and synthesis of the growing body of endplate research to advance related knowledge.

Graphic abstract

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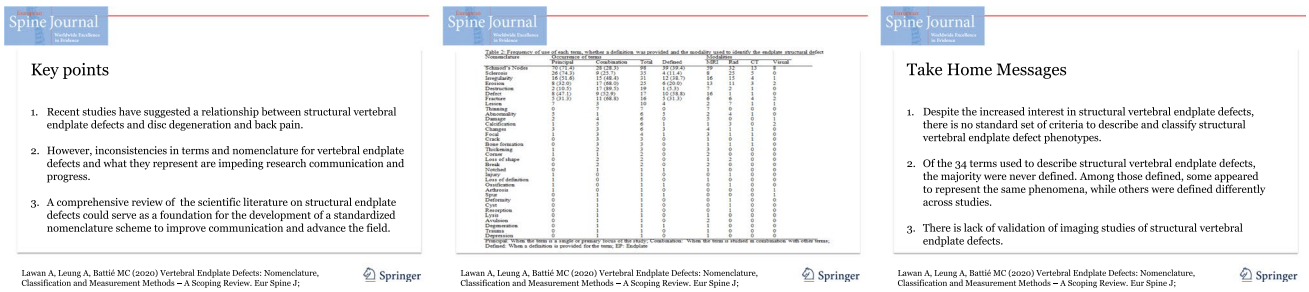

Keywords Endplate · Nomenclature · Measurement · Classification · Psychometric properties · Vertebrae

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Introduction

In the quest for the pathogenesis of back pain, structures of the functional spinal unit (FSU), including the vertebra, intervertebral disc and other osteoligamentous structures, are assumed culpable. Previous studies have focused primarily on the disc, despite being largely avascular and aneural, with many conflicting findings among studies. While disc degeneration has been associated with back pain [1], evidence also shows that disc degeneration is common among individuals without back pain [1, 2], limiting its clinical utility [3]. Advances in imaging are allowing better visualization of spinal structures, such as the endplate, which are increasingly becoming targets of investigation. The endplate is a thin mechanical interface between the vertebral body and disc and serves to absorb the pressure that results from mechanical loading of the spine. Together with the disc, it helps to evenly distribute the compressive load across the vertebral body [4] and is predisposed to mechanical failure [5] that may lead to high stress gradients and precipitate disc degeneration [6, 7].

A previous study [8] noted that findings of disc degeneration are closely linked to changes in the vertebral endplate. Furthermore, Wang et al. [9] found a clear association between endplate defects and both occasional (OR = 8.68, 95% CI 1.13–66.69) and frequent (OR = 17.88, 95% CI 2.48–129.02) back pain that remained after adjusting for disc degeneration. This and other studies [10, 11] have suggested a role for endplate defects in the pathogenesis of back pain. Such evidence has shifted researchers' attention to the endplate, which is more vascular and neural than the disc. It is not clear, however, if all types of endplate defects contribute similarly to the development of pain or specific pathology [12]. There is also a wide range in the prevalence of endplate defects (9–75%) reported across studies. Variations in endplate classification or measurement methods and characteristics of the study subjects may have contributed to inconsistencies in findings [13, 14].

Highlighting the problems associated with discrepancies in endplate research findings, a recent study by Zehra et al. [15] indicated wide variations in endplate nomenclature used among 'expert' clinicians and researchers in naming various endplate structural defects observed on MRI. While other terminology may eventually be preferred, in the absence of consensus on nomenclature, the authors use the general term "endplate defect" when discussing such structural phenomena in the present review. It is possible that the clinical and research ambiguities surrounding endplate defects may be largely due to lack of well-standardized definitions and evaluation criteria, and subsequent heterogeneity of measurement methods [16].

To date, we found no review of literature on nomenclature and classification of structural endplate defects. A systematic search and selection of studies reporting endplate defect nomenclature and measurement methods, and summary of key findings, could serve as the foundation to develop a standardized nomenclature scheme for endplate defects needed to improve the accuracy of communication and the pooling and synthesis of findings across studies to move the field forward.

Methods

This scoping review of the health sciences literature on structural endplate defects was designed according to the standard recommendations of the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (ESM_1.dox: PRISMA checklist), and the literature search was guided using the York framework as proposed by Arksey and O'Malley [17]. The York framework was used in establishing the scope and extent of available literature in the predefined area, endplate defects, in a five-stage process. The protocol for the review was registered at Open Science Framework (https://osf.io/r92ux).

Stage one: the research questions

The research questions were developed based on the purpose of the review. The primary aim of the review was to answer the question: what nomenclatures and phenotypic classifications have been used in determining the presence of endplate defects? The secondary research question was: what measurements have been used to characterize endplate defects and what are their reported psychometric properties?

Stage two: search strategy

An initial search was conducted with a medical and health sciences librarian based on the research questions and prespecified eligibility criteria. The search strategy was further refined iteratively based on the librarian's recommendations and input from spine imaging and endplate research experts. The databases of PubMed, Scopus, Cumulative Index of Nursing and Allied Health literatures (CINAHL), Google scholar and EMBASE were searched. Medical Subject Headings (MeSH) for all the key terms were searched and combined using appropriate combinations of Boolean operators. ESM_2.pdf contains the detailed description of the search strategy for each of the databases used.

Stage three: eligibility and screening

The review includes articles that meet the following inclusion criteria: (1) studies that report on structural endplate defects among human subjects; (2) studies that primarily measure macroscopic endplate defects; and (3) studies that report nomenclature or measurement procedures for the presence, type or extent of endplate defects. Discussion or position papers, commentaries or conference proceedings or abstracts were excluded. The search was not limited by study design or date of publication. Articles from the searched databases (PubMed, Scopus, CINAHL, Google scholar and EMBASE) were compiled and transferred into a citation manager (Endnote). Duplicates were removed, and the remaining articles were then imported into review management software (Covidence; Melbourne, Australia: Veritas Health Innovation), for independent and blinded screening by the reviewers. A series of training exercises were conducted prior to commencing screening. Percent agreement of > 75% between the reviewers was achieved before commencing the screening. Two reviewers then independently screened the identified articles. Also, reference lists of all included articles were checked for additional articles suitable for inclusion, which went through the same review process.

Stage four: data collection and extraction

A developed data extraction form was used and included the following: (1) citation; (2) year of publication, (3) country of origin; (4) study purpose; (5) study design; (6) endplate defect rater (e.g. radiologist, research assistant, etc.); (7) population sample (e.g. patient or general population samples, age and sex distribution, etc.); (8) imaging modality; (9) description of measurement classification and nomenclature; and (10) psychometric properties of the measurements.

Stage five: collating, summarizing and reporting the results

Results of the search were collated, summarized and reported descriptively using figures and tables. Also, descriptive qualitative analyses for themes and content related to definitions of the identified endplate phenotypes were carried out, including use of the software (NVivo) 10 (QSR International Pty Ltd; Doncaster, VC).

Results

Search and selection

Figure 1 shows the flow diagram for the systematic selection of eligible articles for inclusion in the review. The online search of the five databases yielded a total of 2767 citations, of which 395 were identified as duplicates. Following title and abstract screening of the remaining 2372 citations, 2037 citations were identified as irrelevant to the scope of the review. Full texts of the remaining 335 articles were reviewed based on the inclusion criteria, which resulted in the exclusion of 141 articles. Review of the reference lists of the 194 included articles yielded 17 additional articles. Thus, a total of 211 articles were included for the review, for which a detailed summary of characteristics is presented in ESM_3.pdf.

Characteristics of the included studies

Table 1 shows the characteristics of the 211 included studies of Schmorl's nodes and other nomenclatures. These studies originated from 29 countries, with the greatest number of contributions from the USA (18.8%), China (12.3%) and Japan (10.8%), while Canada and Finland contributed 6.6% each. The publication dates ranged from 1976 to 2019, with more than 55% of the studies published within the last decade (2010–2019). Retrospective and prospective cohort ($n = 95$, 45.0%) were the most common study designs used. Studies on patients were the most frequent ($n = 109$, 51.7%), followed by general population samples ($n = 65$, 38.8%).

One hundred and thirty-seven (64.6%) of the included studies did not offer defining criteria for at least one term used to describe endplate defects. Of those studies that investigated only presence or absence of endplate phenotypes, few (26.4%) provided further explanation, which was based on severity, location or size (Table 1). A few studies ($n = 9$) used a composite score, and one study used an automated algorithm for Schmorl's nodes. Most of the studies used MRI (42.4%) or radiographs (35.2%) to identify endplate defects, while visual inspection (5.2%) was the least common approach. There was a similar distribution in study characteristics relating to design, population, age and reported psychometrics, across the groups of studied endplate phenotypes, but not with respect to whether terms were defined and the imaging modality used. Studies that focused on only Schmorl's nodes provided definitions more often (49.3%) than studies of other phenotypes (27.4%) or studies that included more than one type of endplate phenotype (32.1%). They also used MRI more frequently and radiographs less frequently to determine defects (Table 1).

Terms used to denote structural endplate defects

Table 2 shows the frequency that each term was used for a particular structural endplate defect and how often definitions were provided. A total of 34 terms were used in 54 different combinations in the review. Nineteen terms were the sole focus in 161 studies, while the remaining 51 studies

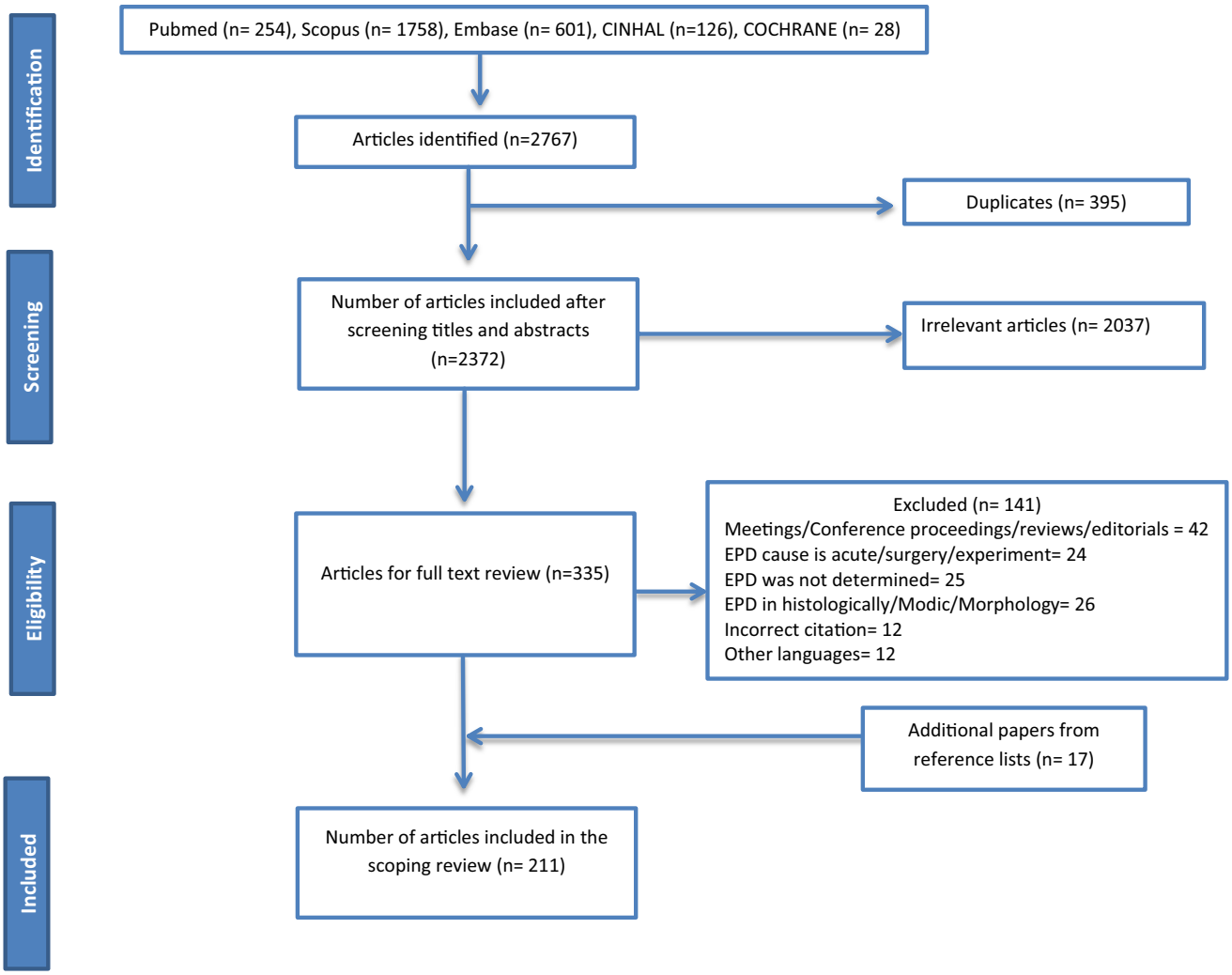

Fig. 1 Flowchart of study selection and inclusion

described endplate defects in 35 different combinations. Schmorl's nodes, sclerosis and endplate irregularity were the most common terms studied, appearing in 99, 35 and 31 studies, respectively. The most common combination studied was Schmorl's nodes and endplate irregularity in eight studies. Furthermore, Schmorl's nodes, endplate irregularity and endplate defect were the terms for which a definition was most frequently provided.

Definitions of structural endplate defects

Table 3 provides the definitions of the terms used to describe endplate defects in the publications included in the review. A qualitative analysis identifying themes through auto-coding using NVivo software was conducted for Schmorl's nodes, the most frequently defined term, after extracting each definition manually. Twenty-six studies have defined Schmorl's node using at least one of the four identified themes, while the remaining 13 studies define the term in other ways, such as a depression with sclerotic margins on the vertebral body surface [18] and as "apparent depressions of ruptures of disc material into the subchondral bone, regular or irregular in shape" [19].

The four thematic words may be grouped into two categories, irregularities and defects vs herniation and indentation, used interchangeably in the majority of definitions. Fourteen studies defining Schmorl's nodes as being either an indentation or herniation further described them as focal or localized defects. However, two studies [20, 21] specifically noted only defects of $\geq$ 3 mm size can be considered as Schmorl's nodes. Other studies referred to Schmorl's nodes as endplate lesions [22, 23] or a bony defect in the vertebral endplate without signal-intensity alteration [24]. The majority of the definitions of Schmorl's nodes are similar in meaning, except for the description of the margin of the herniation, indentation or

Table 1 Characteristics of all included studies, and those of only Schmorl's nodes, other types of endplate defects, and combinations of the two

Characteristics	Total ($n=211$)	Schmorl's ($n=70$; 34%)	Other defects ($n=113$; 53%)	Combination ($n=28$; 13%)
Study design				
Case report	23 (10.9)	7 (10.0)	13 (11.5)	3 (10.7)
Case series	12 (5.7)	4 (5.7)	8 (7.1)	0
Case control	16 (7.6)	9 (12.9)	5 (4.4)	2 (7.1)
Cohort	95 (45.0)	29 (41.4)	54 (47.8)	12 (42.9)
Population-based	34 (16.1)	13 (18.6)	19 (16.8)	2 (7.1)
Cadaveric	28 (13.3)	8 (11.4)	12 (13.3)	8 (11.4)
Delphi	1 (0.5)	0	1 (0.9)	0
RCT	2 (1.0)	0	1 (0.9)	1 (3.6)
Age				
Young	23 (10.9)	4 (5.7)	14 (14.4)	5 (20.0)
Adult	31 (17.3)	17 (29.8)	12 (12.4)	2 (8.0)
Old	16 (7.6)	3 (4.3)	12 (12.4)	1 (4.0)
Mixed	108 (51.29)	32 (45.9)	59 (60.8)	17 (68.0)
Modality				
MRI	88 (41.7)	39 (56.3)	39 (35.9)	10 (35.7)
Radiograph	74 (35.2)	12 (16.9)	51 (46.0)	11 (39.3)
CT	14 (6.67)	5 (7.0)	7 (6.3)	2 (7.1)
Visual inspection	11 (5.2)	6 (8.5)	3 (2.7)	2 (7.1)
Mixed	22 (10.5)	8 (11.3)	11 (9.9)	3 (10.8)
Definition/explanation				
Yes	74 (35.1)	34 (48.6)	31 (27.4)	9 (32.1)
No	137 (64.9)	36 (51.4)	82 (72.6)	19 (67.9)
Grade/classification				
Presence/absence	155 (73.5)	64 (91.4)	76 (67.3)	16 (57.1)
Severity	25 (11.9)	1 (1.4)	20 (17.7)	4 (14.3)
Location	8 (3.8)	0	7 (6.2)	1 (3.6)
Size	8 (3.8)	2 (2.9)	2 (1.8)	4 (14.3)
Type	2 (1.0)	1 (1.4)	1 (0.9)	0
Composite score	9 (4.3)	1 (1.4)	6 (5.3)	2 (7.1)
Automated score	1 (0.5)	1 (1.4)	0	0 (0)
Mix	3 (1.4)	1 (1.5)	1 (0.8)	1 (3.6)
Psychometric properties				
Not reported	150 (71.1)	50 (71.4)	81 (72.3)	14 (50.0)
Intra-rater	14 (6.6)	0	8 (7.1)	6 (21.4)
Inter-rater	17 (8.1)	6 (8.6)	10 (8.9)	1 (3.6)
Intra- and inter-rater	29 (13.7)	9 (12.9)	13 (11.6)	7 (25.0)

Age: young = < 18; adult = > 18 to < 59; old = ≥60; mixed = all age groups included

depression as to the presence of a sclerotic margin or rim, or osseous casing (19 out of the 39 studies).

Definitions of *endplate sclerosis* were fairly similar among the four studies providing definitions and included hypertrophy [25], irregular mineralization [26], radiographic density area, width and breadth [27] or densification [28] of the endplate. The definition of *endplate fracture* appeared to fall into one of two groupings, with one describing abnormal angulations of at least 50% [29], a well-corticated bone fragment [30] or a displaced fracture line [31], and the other grouping describing linear defects [12], clefts or fissures [16].

There was apparent confusion on what constitutes *endplate erosion* from the six definitions used in the 25 published studies of endplate erosion. Two studies defined erosion as a worm-eaten appearance or pattern, or more specifically as an "extensive alteration in the endplate as depicted by an irregular, serrated, or worm-eaten appearance" [32] or as "thin lytic lesions frequently showing a worm-eaten aspect" [9]. Other definitions included a diffuse

Table 2 Frequency of use of each term, whether a definition was provided and the modality used to identify the endplate structural defect

	Nomenclature	Occurrence of terms				Modalities			
		Principal	Combination	Total	Defined	MRI	Rad	CT	Visual
1.	Schmorl's nodes	70 (71.4)	28 (28.3)	98	39 (39.4)	59	32	13	8
2.	Sclerosis	26 (74.3)	9 (25.7)	35	4 (11.4)	8	25	5	0
3.	Irregularity	16 (51.6)	15 (48.4)	31	12 (38.7)	16	15	4	1
4.	Erosion	8 (32.0)	17 (68.0)	25	6 (20.0)	13	11	3	2
5.	Destruction	2 (10.5)	17 (89.5)	19	1 (5.3)	7	2	1	0
6.	Defect	8 (47.1)	9 (52.9)	17	10 (58.8)	16	1	1	0
7.	Fracture	5 (31.3)	11 (68.8)	16	5 (31.3)	6	6	4	2
8.	Lesion	7	3	10	4	2	7	1	1
9.	Thinning	0	7	7	0	7	0	0	0
10.	Abnormality	5	1	6	5	2	4	1	0
11.	Damage	2	4	6	0	5	0	0	1
12.	Calcification	1	5	6	1	1	3	0	2
13.	Changes	3	3	6	3	4	1	1	0
14.	Focal	1	3	4	1	3	1	1	0
15.	Crack	0	3	3	0	1	0	1	0
16.	Bone formation	0	3	3	0	1	1	1	0
17.	Thickening	1	2	3	0	3	0	0	0
18.	Corner	1	1	2	0	2	0	0	0
19.	Loss of shape	0	2	2	0	1	2	0	0
20.	Break	0	2	2	0	2	0	0	0
21.	Notched	0	1	1	1	1	0	0	0
22.	Injury	1	0	1	0	0	1	0	0
23.	Loss of definition	1	0	1	0	1	0	0	0
24.	Ossification	1	0	1	1	0	1	0	0
25.	Arthrosis	1	0	1	0	0	0	0	1
26.	Spur	0	1	1	1	0	0	0	1
27.	Deformity	0	1	1	0	0	1	0	0
28.	Cyst	0	1	1	0	0	1	0	0
29.	Resorption	0	1	1	0	0	1	0	0
30.	Lysis	0	1	1	0	1	0	0	0
31.	Avulsion	0	1	1	0	2	0	0	0
32.	Degeneration	0	1	1	1	1	0	0	0
33.	Trauma	0	1	1	0	1	0	0	0
34.	Depression	0	1	1	0	1	0	0	0

Principal: when the term is a single or primary focus of the study; combination: when the term is studied in combination with other terms

Defined: when a definition is provided for the term; EP: endplate

shallow defect with irregular appearance [12] or abnormal fibrocartilage ingrowth [33]. Erosion was related to thinning of the endplate in three studies, such as an "irregular endplate with thinning or loss of visualization of the subchondral cortical plate" [29], "a loss of full-thickness of the dark appearance of the cortical bone and loss of normal bright appearance of the adjacent bone marrow" [34] or as a thin lytic lesion [16].

Endplate irregularity was defined as appearing convex, jagged and rough due to intensive calcification [6] or as Schmorl's nodes [35], or as focal indentation similar to Schmorl's nodes (96), or discontinuous disruption similar to fracture [36]. Other definitions excluded structural defects and noted an endplate being intact but irregular (46, 48) or as having no specific lesion, but showing alteration with respect to the physiologic curvature [30]. Some studies also specified location, for example, affecting the middle portion [37]. Ten studies defined an *endplate defect*, using other terms, such as Schmorl's nodes [38, 39], irregularity [38], sclerosis and erosion [40], indentation or discontinuity [41, 42], and as a focal or sharp depression [39, 43–45]. Two other studies [38, 44]

Table 3 Definitions used to describe endplate defect terms and measurement reliability, when reported

Terms	Definition	Intra-rater (*n* studies)	Inter-rater (n studies)
Schmorl's	Localized or focal indentation, depression or herniation of the disc into the endplate with sclerotic margin [1, 21, 25, 34, 35, 45, 48, 56, 61, 62, 68, 110, 136, 139, 141, 161]	0.8–0.94 (3)	0.8–0.9 (4)
	Localized or focal indentation, depression or herniation of the disc into the endplate [10, 23, 103, 131, 140, 145, 164, 167, 171, 179, 196, 200, 26, 207, 52, 66, 77, 86, 88, 90, 94]	0.88 (1)	0.3–0.91 (6)
Sclerosis	Changes in maximum intensity as areas of irregular mineralization or hypertrophy or densification or radiographic density, area, width and thickness of the end plates [4, 37, 84, 174]	0.92 (1)	0.92 (1)
Fracture	Well-corticated fragment or displaced fracture line [21, 28]	0.89 (1)	0.73 (1)
	Fissure, cleft or linear defect [161, 171]	0.80 (1)	
	Abnormal angulations of at least 50% of the anteroposterior [179]		
Erosion	Bony erosion and abnormal fibrocartilage ingrowth [17]		
	Characterized by extensive alteration of the endplate as depicted by an irregular, serrated, or worm eaten appearance or as thin lytic lesions frequently showing a worm-eaten aspect [42, 161]	0.72–0.82 (2)	0.51–0.61 (1)
	Full-thickness loss of the dark appearance of cortical bone and loss of normal bright appearance of adjacent bone marrow on T1w [117]		
	Diffuse, shallow defects with an irregular appearance [171]		
	Irregular appearance of the endplate with thinning or focal loss of visualization of the subchondral cortical plate [179]		
Defects	Sharp indentations or discontinuity of the cortical bone [9]	0.74 (1)	0.53 (1)
	Presence of at least one Schmorl's node or irregular endplate they are defined as mostly roundish chondroid disc defects in the centre or anterior aspect of the vertebral endplates with sclerotic rim OR undulating irregularities mainly on anterior aspects; one or more vertebral levels [11]	0.59 (1)	0.70 (1)
	As the loss or disruption of the smooth appearance of the endplate visible on at least two consecutive sagittal MR images [42]	0.72–0.82 (1)	0.51–0.61 (1)
	sharp depressions of the endplate contour as endplate defects [114]		
	Focal depression along the endplate in the form of a Schmorl's nodes was considered as an end plate defect [134]		0.57–0.86 (1)
	Spread of the dye through the cartilaginous endplates in discography [142]		
	As focal endplate defect (herniation of the intervertebral disc into the endplate and the adjacent vertebral body, also called Schmorl's nodes) or irregularity involving the entire endplate [147]		
	As any localized morphologic feature of the osseous anatomy that could not be explained by the overall shape of the endplate, recognizing that endplates can have a variety of morphologies [163]		
	Sclerosis and erosion [175]		
	Defects were defined as "sharp" indentations or discontinuity of the cortical bone [184]	0.56 (1)	0.59 (1)
Irregular	As endplates that were intact but irregular [9]		
	As Schmorl's nodes [20]		
	No specific lesions are detectable in the intervertebral space. However, the shape of at least one of the endplates shows alterations with respect to the physiological curvature [21]	0.89 (1)	0.73 (1)
	Fractures (discontinuous disruption and other focal deviations of the VEP contour from the norm [23]		
	Undulating irregularities of vertebral body endplates [45]	0.71 (1)	0.76 (1)
	Sawtooth-like or wave-like on MR [88]		
	Including Schmorl's nodes which are actually focal indentations of the vertebral endplate [96]		
	Irregular if excrescencies were seen above the edge, and concave if disc was visible between the ruler and the end plate [118]		
	Appeared convex, jagged or rough due to intensive calcification [158]		

Table 3 (continued)

Terms	Definition	Intra-rater (*n* studies)	Inter-rater (n studies)
	As endplates that where intact, but irregular [184]	0.52 (1)	0.52 (1)
	When the linearity and integrity of the middle portion of an endplate was lost on a sagittal MR image [198]		
	if the endplate seemed convex, jagged, or rough due to calcification [204]	0.91–0.96 (1)	0.87–0.93 (1)
Abnormality	Disruption of the inferior endplate of the vertebra above or the superior endplate of the vertebra below including Schmorl's nodes [19]	0.96 (1)	
	Irregularity or discontinuity, disc abnormalities (Schmorl's nodes) [33]		
	such as Schmorl's nodes, irregularity and epiphyseal separation [99]		
	Variable notching and anterosuperior ossification defects [123]		
	Irregular vertebral borders, sclerosis, disc space narrowing, and anterior cystic changes [127]		
Lesion	Ossified fragment [55]		
	Endplate lesions were diagnosed based on area of the lesion (i.e. osseous fragment and deformity of the endplate [153]		
	Radiologically as a discontinuity in the cartilaginous part of the vertebral end-plate (the part enclosed within the vertebral rim) associated with a translucency in the adjacent vertebral body [208]		
	A focal depression was evident in the L5 upper epiphyseal plate. The lysis was surrounded by a thin sclerotic margin, which suggested the presence of a nonaggressive lesion [209]		
Changes	Small cysts, erosion, and bone tissue resorption [130]		
	Any osseous disruption of the superior or inferior vertebral endplate on CT that could not be explained by the overall shape of the endplate, recognizing the variation in morphology among vertebral endplates [199]		
	Areas of end plate abnormalities, irregularities, or defects, in which the border of the vertebral end plate was indented into the vertebral body [85]		0.92 (1)
Calcification	Wide accumulation of calcium upon the endplate, which assumes a rough appearance [158]	0.80 (1)	
	Intensive calcium deposition upon the endplate [161]		
Destruction	As erosion was defined as irregularity of margins of vertebral body endplates [64]		
Notched	A V-shaped or circular small lesion visible in at least one sagittal MRI slice [21]	0.89 (1)	0.73 (1)
Focal	Focal: local hollow or discontinuity on the endplate, with nucleus protrusion into the subchondral bone [42]	0.72–0.82 (1)	0.51–0.61 (1)
Ossification	Bony end-plate thickness was greater than 2 mm on lateral view [60]		
Spur	A bright signal on T1w images extending from the vertebral endplate towards the adjacent vertebra [117]		
Degeneration	Bone-annulus interface, including bone marrow changes and loss of annular fiber organization [17]		

Reference numbers correspond to the complete reference list in the supplementary file

considered endplate defects as irregularities involving the entire endplate.

The term *lesion* was mentioned in 10 studies, of which four studies provided a definition, including an ossified or osseous fragment [46, 47], a discontinuity in the cartilaginous endplate [48], and a focal depression with sclerotic margins [49]. *Endplate changes* were defined as areas of endplate abnormalities, irregularities or defects, in which the border of the vertebral endplate was indented into the vertebral body [50], or as small cysts, erosion, bone resorption and disruption [51]. The term *endplate abnormality* was used as a global term, further defined in four studies as disruption of the endplate, including Schmorl's nodes [52], irregularity, discontinuity or Schmorl's nodes [53], notching and ossification [54], sclerosis and cystic changes [55]. Some terms used to describe structural endplate defects were defined only once (Table 3).

Measurement reliability and advanced measurement methods

The majority (71.6%) of the studies reported no psychometric properties of the endplate measurements used. Of

the relatively few studies reporting psychometric properties, 14 (6.6%) reported only intra-rater reliability, 17 (8.1%) reported only inter-rater reliability, and 29 (13.7%) studies reported both. With respect to psychometric properties of defect measurements using the different imaging modalities, intra- and inter-rater reliability kappa coefficients for the various defect measurements ranged from 0.52–0.94 and 0.30–0.92, respectively (Table 3).

Thirty-one studies reported reliability of measurement methods using MRI in identifying endplate defects of 0.69 ± 0.2 and 0.78 ± 0.12 for intra- and inter-rater reliability coefficients respectively. Radiographs were used in 23 studies with an average of 0.64 ± 0.23 and 0.75 ± 0.18 for inter- and intra-rater reliability coefficients, respectively. No studies reported the inter-rater reliability for visual inspection, while 5 studies reported intra-rater reliability coefficients of 0.81 ± 0.03. Few ($n = 2$) studies reported the reliability using CT with a mean value of 0.9 and 0.94 for the inter- and intra-rater reliability, respectively.

Four advanced measures of endplate defects were reported in nine studies. One method reported a combination of both histologic and macroscopic defects and the others reported macroscopic structural defects and Modic changes. Total endplate (TEP) score was the most reported [56–61] scoring method of grading endplate defects, which demonstrated "strong" inter-rater agreement (weighted kappa = 0.80 to 0.88) according to Cohen's kappa interpretation by McHugh [62]. Kanna et al. [56] showed a positive correlation in TEP score with degree of disc degeneration, which was significantly higher with disc prolapse (7.6 ± 3.1) than without prolapse (5.0 ± 2.2, $p < 001$). Also, Rade et al. [61] found that a TEP score of ≥ 5 was strongly and independently associated with disc degeneration at all spinal levels and was a confounder for the association between disc degeneration and age and BMI.

Furthermore, Zehra et al. [63] studied endplate structural defects in terms of maximum width and depth. Both width and depth of all endplate defects in each subject were added separately, and scores were assigned on the basis of size from 1 to 3. Combining both scores provided a cumulative endplate defect score of 1 to 6. "Strong" and "almost perfect" inter-rater reliability was reported for endplate defect width ($k = 0.84$) and depth ($k = 0.93$) measurements, respectively. Hilton et al. [48] also graded endplates on a 0–3 scale according to the size and depth of the lesion. At each disc, the grades for lesions at the upper and lower vertebral endplates of a disc were summed for a maximum endplate lesion score out of 6. Also, an automated computer-based measurement algorithm was used to determine and calculate Schmorl's nodes dimensions using the eRAD PACS Viewer for a study by Yin et al. [64]. Tomaszewski et al. [65] and Boos et al. [66] reported on Boos' classification for endplate degeneration that includes both histologic and macroscopic examinations. Six domains were analyzed for the classification including cell proliferation (0 to 4), cartilage disorganization (0 to 4), cartilage crack (0 to 4), micro-fracture (0 to 2), new bone formation (0 to 2) and bony sclerosis (0 to 2). Inter-rater reliability across the domains ranged from 0.79 to 0.87.

Discussion

There has been an increased growth in published literature related to structural endplate defects, especially within the last decade. Various terms were used to describe endplate defects either as a single study focus or in combination with other terms. Only 35.4% of studies defined the terms, and when definitions were provided, there were frequently inconsistencies in meaning between studies using the same terms. In other cases, different terms appeared to be referring to the same phenotype. Most studies did not report the psychometric properties of the endplate defect measurements used, and only intra- and inter-rater reliability were ever reported.

The different terms used to denote structural defects in the endplate varied in frequency of use and pattern of occurrence. Terms used most frequently may represent more developed concepts of structural defects and wider acceptability than those less frequently used. For example, Schmorl's node was the most commonly studied defect, either as a single study focus or in combination with other phenotypes. This finding is not surprising considering that Schmorl's node was the first recognized form of endplate defect [67]. Otherwise, published studies of other endplate defect terms and phenotypes typically lack strict definition criteria that vary between studies.

Standardizing the defining criteria to establish the content validity of an outcome is usually one of the first stages in the validation process. As mentioned, Schmorl's nodes have been extensively studied and defined and the use of similar themes for the definitions is consistent with the content meaning. However, variations in consideration of the margin, such as presence of a sclerotic or darkened margin, in the definition may influence what Schmorl's nodes represent and may alter the frequency and types of findings reported. Also specifying the size (> 3 mm) of the herniation or "node" to qualify as a Schmorl's node [21] may enable harmonization or differentiation of other terms, such as focal defect. Sclerosis is another term with fairly consistent definitions in the literature; however, other terms used, such as calcification [9] and ossification [68], may represent the same concept as sclerosis. On the other hand, the term endplate erosion is disparately described as a worm-eaten pattern [9, 32], a diffuse shallow defect with irregular appearance [12], abnormal fibrocartilage ingrowth [33], or an irregular endplate thinning including loss of full thickness [29, 34]. There

is a clear need for a consensus on such specific terms and their definitions.

For lack of an agreed upon umbrella term, "endplate defect" has been used in this review to represent structural endplate phenomena broadly. The term defect has been used to represent a range of endplate findings in the literature, including Schmorl's nodes [38, 39], sclerosis, erosion [40] and fracture [41, 42], which may be localized or spread to the entire endplate [38, 44]. Other terms that have been used to represent a wide range of endplate defects include endplate irregularities, lesions, abnormalities and changes, suggesting the need for a broadly accepted umbrella term to represent endplate abnormalities or defects. Specifically with respect to the term lesion, considering its literal meaning "as damage caused by injury or disease", perhaps this might exclude other forms of endplate alterations that are developmental. Also, changes represent a term synonymous to becoming different from the original state implying a temporal association, which may limit its use as such an assumption cannot always be made, at least in studies with measurements at only one time point (e.g. cross-sectional studies). Agreement on a general umbrella term to represent any endplate structural defect is needed.

Not surprisingly, imaging of endplate defects has shifted from radiography to MRI. Radiography offers excellent bone detail and has long been widely available and low cost. CT can provide even more information about bone structure. However, both modalities require ionizing radiation to form images, while MRI does not. The safety benefit of MRI, along with advances in image quality and greater availability, has led to its increased use. The shift in imaging modality may also account, in part, for differences in the description of endplate defect phenotypes.

Among the cadaveric studies, the classification (Schmorl's node, calcification, erosion and fracture) by Wang et al. [9] was the system most frequently used [9, 10, 16]. Despite the certainty of visual inspection in determining endplate structural defects, the method has obvious limited clinical applicability and a subsequent classification scheme (normal, wavy/irregular, notched, Schmorl's node and fracture) was developed for use in the clinical setting [30]. While "strong" intra-rater reliability (kappa 0.89) was reported according to Cohen's kappa interpretation by McHugh [62], there is currently no validation study that has compared the accuracy of the endplate defect measurements on imaging to visual inspection.

To our knowledge, this is the first review to examine the scope of measurement methods and terms used to define structural endplate defects in the health sciences literature. However, there are some limitations to our review. For example, only full-text research articles were included in the review. The authors acknowledge that the first publication of endplate defects may not correspond to the year of the first publication of our included studies, as full text may not have been accessible through any databases. Also, we did not include full text papers in languages other than English. However, this limitation is unlikely to have substantial impact on our review, as only a few non-English papers were identified and we traced the significant findings and focus of the papers from the English abstracts. Finally, we did not incorporate critical appraisal of the included studies, for which there is some disagreement for scoping reviews. Arksey and O'Malley [17] state that systematic reviews aimed at a narrow range of evidence may require quality assurance, while a scoping review is less likely concerned with a specific question and, therefore, quality assessment may be of less benefit. Though there may be a pattern in the reliability estimates among the imaging modalities and nomenclature used to identify endplate defects, conclusions are limited by varied and ill-defined endplate defect phenotypes and other insufficient methodological information, which further limits our ability to determine the extent of bias and internal validity of those studies.

Conclusion

Despite increased interest in endplate structural defect phenotypes and advances made in imaging within recent decades, there is no standard set of criteria to describe and classify different endplate structural defects. There is also a lack of validation studies that compare observations on imaging to actual tissue samples. This review highlights the need for standardized endplate nomenclature, definitions and measurement methods, as well as the need to validate the measurement methods in order to ascertain with confidence what each of the phenotypes actually represents. Our hope is that this review provides a foundation and impetus to take the necessary steps to meet this need to improve communication and synthesis of the growing body of endplate research to advance the field.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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