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ORIGINAL RESEARCH

Atlas for the CT Syndesmophyte Score (CTSS) in patients with axial spondyloarthritis

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ABSTRACT

Background: The Computed Tomography Syndesmophyte Score (CTSS) was developed as a reliable and sensitive tool to assess syndesmophytes in low-dose CT images of the entire spine in patients with axial spondyloarthritis (axSpA). The original paper provided sparce examples of the CTSS grades.

Objectives: Provide an atlas tailored to assist readers in understanding and employing the CTSS method.

Methods: In this paper, illustrations of the different grades and views of the CTSS are presented. CTSS is used to measure bone formation in the spine of patients with axial spondyloarthritis (axSpA), in the form of syndesmophytes. In both the sagittal and coronal planes, syndesmophytes can be graded from 0 to 3 over 23 vertebral units starting at C2 and ending at S1. The CTSS ranges from 0 (absence of axSpA-related syndesmophytes) to 552 (total ankylosis of the spine).

Results: The current atlas contains low-dose CT images of the spine without lesions (for reference) and all grades of syndesmophytes in different planes used in the CTSS. Examples are arranged per spinal segment (cervical, thoracic and lumbar).

Conclusions: These images can be used to assist any reader in the assessment of syndesmophytes on (low-dose) CT in patients with axSpA.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The CT Syndesmophyte Score (CTSS) was developed in 2017 as a reliable and sensitive tool to cross-sectionally (and longitudinally) assess the presence (and progression) of syndesmophytes in patients with axial spondyloarthritis (axSpA).

⇒ The original paper provided limited illustrative examples of the CTSS grades.

WHAT THIS STUDY ADDS

⇒ An atlas specifically tailored to assist readers in understanding and employing the CTSS method.

⇒ This atlas contains a large range of meticulously curated images, from normal to damaged spine (syndesmophytes) across different spinal segments and planes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ These images serve as practical references to aid readers in effectively assessing syndesmophytes using (low-dose) CT scans in patients with axSpA.

⇒ This atlas sets the basis for precise and reliable CTSS assessment, thereby enhancing the external reproducibility and quality of research when employing this score.

INTRODUCTION

Axial spondyloarthritis (axSpA) is a chronic inflammatory rheumatic disease of the axial skeleton that leads to new bone formation of the spine in the form of syndesmophytes.[1] These ectopic bone formation lesions embody the irreversible consequences of the disease and are associated with a significant burden. As such, syndesmophyte growth is associated with impairment of spinal mobility and functional disability.[2 3]

As an improvement over conventional radiography which has been the standard for imaging syndesmophytes in axSpA for many decades,[4 5] low-dose CT facilitates the comprehensive assessment of syndesmophytes in the entire spine using acceptable levels of radiation exposure. A major advantage of this method is the assessment of the thoracic spine, which is challenging to evaluate on radiographs due to the superposition of structures, particularly the ribs.[6]

In 2017, low-dose CT scans from patients with axSpA from the Sensitive Imaging in Axial Spondyloarthritis (SIAS) cohort were used to develop the CT Syndesmophyte Score (CTSS), which assesses syndesmophytes from C2 to S1.[7 8] CTSS has shown to be a reliable and sensitive tool to cross-sectionally (and longitudinally) assess the presence (and progression) of syndesmophytes in patients with axSpA.[7 8]

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Table 1 Description of the CT Syndesmophyte Score (CTSS) method

Spinal segments assessed	
Cervical spine	Lower half of C2 to upper half of T1
Thoracic spine	Lower half of T1 to upper half of T12
Lumbar spine	Lower half of T12 to upper half of S1
Scoring grades	
0	No abnormalities
1	Syndesmophyte height<50% of IDS
2	Syndesmophyte height≥50% of IDS but not bridging
3	Bridging syndesmophyte
Definitions of syndesmophyte progression	
New	Score 0→1, 2, 3
Growth	Score 1→2, 3 or 2→3

Adapted from de Koning *et al*.[8]
IDS, intervertebral disc space.

Developments in CT detector technology,[9] special filters[10 11] and modern (AI-based) reconstructions algorithms,[12] promise further reduction of ionising radiation for CT scans. Moreover, with a worldwide increased accessibility of low-dose CT, used in other diseases, namely for cancer screening,[13] we may anticipate an upsurge of its usage in patients with axSpA, especially for research purposes.

Assessment of the entire spine using the CTSS method may pose challenges for inexperienced readers. The original paper by de Bruin *et al* described the score, but only limited examples were presented.[7] Clear guidance on how to use the CTSS throughout the whole spine is crucial to guarantee its external reproducibility.

This paper discusses basic radiological concepts with relevance for any reader. An atlas is presented for the CTSS, with representative images for the normal spine along with reference images of different syndesmophyte grades. Examples are shown on different vertebral unit (VU) levels and in both sagittal and coronal planes. Any reader can use these reference images as examples to assist the assessment of syndesmophytes on (low-dose) CT in patients diagnosed with axSpA.

Scoring assessment

A schematic overview of the CTSS is shown in table 1 (adapted from de Koning *et al*).[8] In the CTSS scoring method, 23 VUs are assessed starting with the lower half of C2 and ending at the upper half of S1. A VU consists of the lower half of a vertebra, the intervertebral disc space (IDS) and the upper half of the next vertebra (eg, VU1 encompasses the lower half of C2 and the upper half of C3).

Each VU is divided into quadrants and each image is scored in the sagittal and coronal planes (figure 1—adapted from de Bruin *et al*).[7] The sagittal and coronal planes complement each other and must both be assessed from C2 to S1. By scrolling through coronal images, the reader assesses the left and right quadrants of the VU. In the sagittal plane, the reader assesses the anterior and posterior quadrants. These independent assessments should be performed in a standardised way. Ideally, a VU is assessed in both planes before moving to the next VU, evaluating the VUs from top to bottom of the spine.

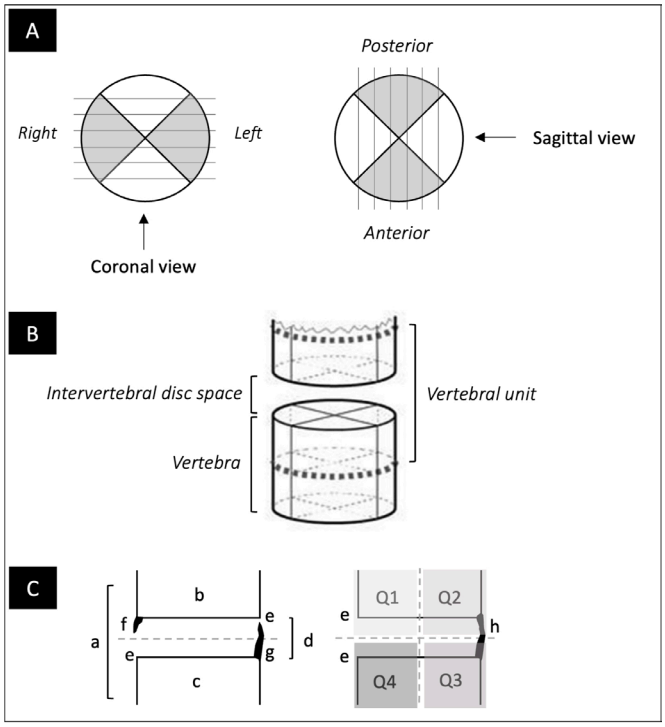

Figure 1 Graphic representation of the views on low-dose CT of sagittal and coronal planes, vertebral unit definition and syndesmophyte scores according to the CTSS. Adapted from de Bruin *et al*.[7] (A) In the coronal plane, the left and right rim of a vertebra can be assessed. In the sagittal plane, the anterior and posterior rim of a vertebra can be assessed. Both the coronal and sagittal planes are assessed. (B) A vertebral unit consists of the lower half of a vertebra, the intervertebral disc space (IDS; with the intervertebral disc) and the upper half of the next vertebra. (C) Schematic views of vertebral units with syndesmophytes. Depicted on the left is a vertebral unit (a), with the upper (b) and lower (c) halves of the vertebral bodies, and the IDS (d). Some corners had no syndesmophytes (e). Syndesmophytes not reaching the middle of the IDS should be assessed as grade 1, example originating from the upper left corner (f). Syndesmophytes surpassing the middle of the IDS should be assessed as grade 2, example originating from the right lower corner (g). Represented on the right image, we can see a bridging (grade 3) syndesmophyte (h). Syndesmophytes should be assessed in four quadrants per VU, in both the coronal and sagittal planes, combining the total of eight quadrants per VU.

Per VU, eight quadrants are assessed for the presence of syndesmophytes using a 0–3 grading score: '0' if syndesmophytes are absent (figures 2 and 3), '1' when syndesmophyte height is <50% of the IDS (figures 4 and 5), '2' when syndesmophyte height reaches ≥50% of the IDS (figures 6 and 7) and '3' if the syndesmophyte is bridging the IDS (figures 8 and 9). Of note, a score of '3' is, by definition, assigned to both quadrants on opposite sides

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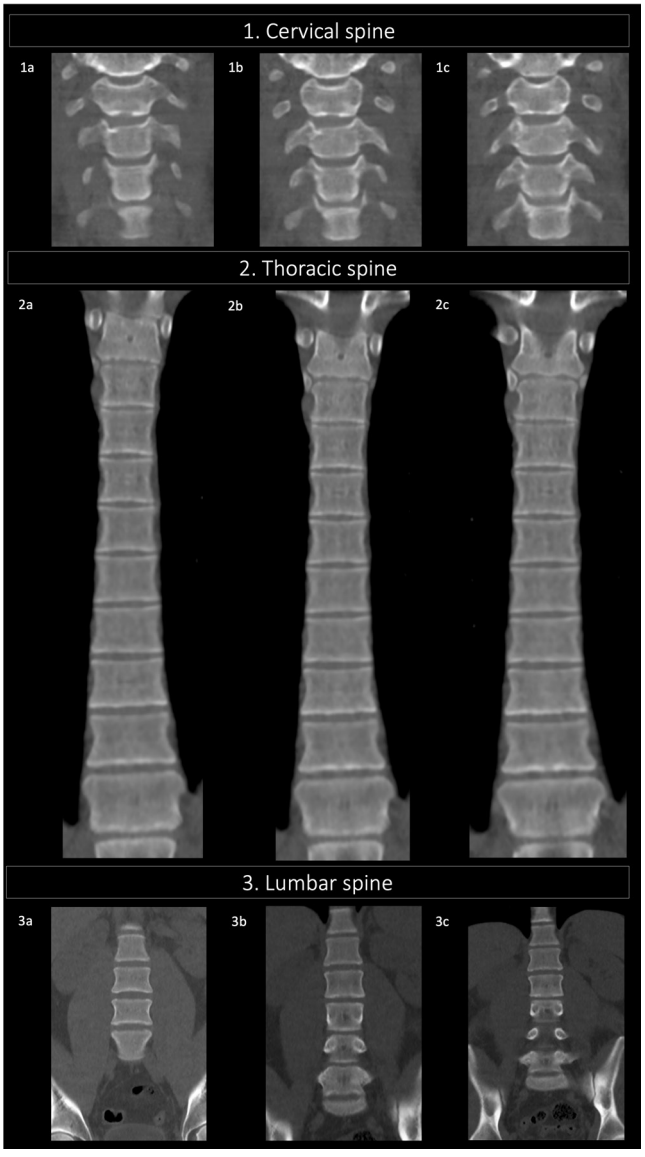

Figure 2 Coronal view of a normal spine with no abnormalities by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c).

of the IDS, for example, upper and lower left quadrants (coronal view) or upper and lower anterior quadrants (sagittal view). The total range of the CTSS, including combined scores of coronal and sagittal quadrants, goes from 0 (absence of SpA-related syndesmophytes) to 552 (total ankylosis of the spine).[7] Facet joint abnormalities are not included in the CTSS.

The judgement on whether abnormalities are present should be guided by the normal shape of each vertebra (representative examples are given in figures 2 and 3). Interpatient and intervertebra (within the same patient) normal anatomic variations of the vertebral shape may occur. Typical examples comprise the U-shaped vertebrae in the coronal plane of the cervical spine, where the normal sloped vertebral corners cannot be mistaken as syndesmophytes (images 1a to 1c of figure 2 and image 1c of figure 4). Moreover, in the sagittal plane of the lumbar spine, the endplate may exhibit a concave/convex shape,

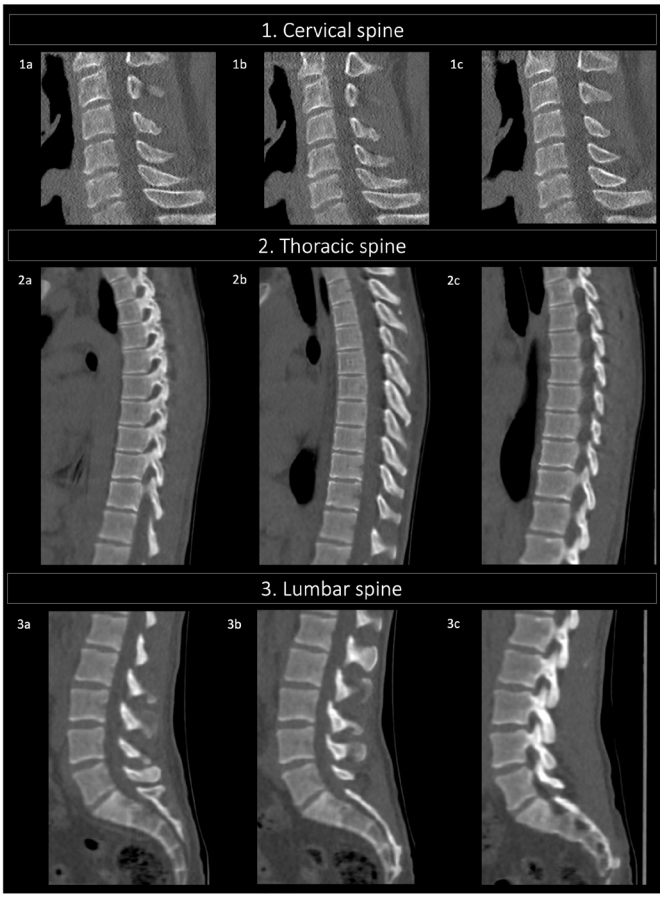

Figure 3 Sagittal view of a normal spine with no abnormalities by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c).

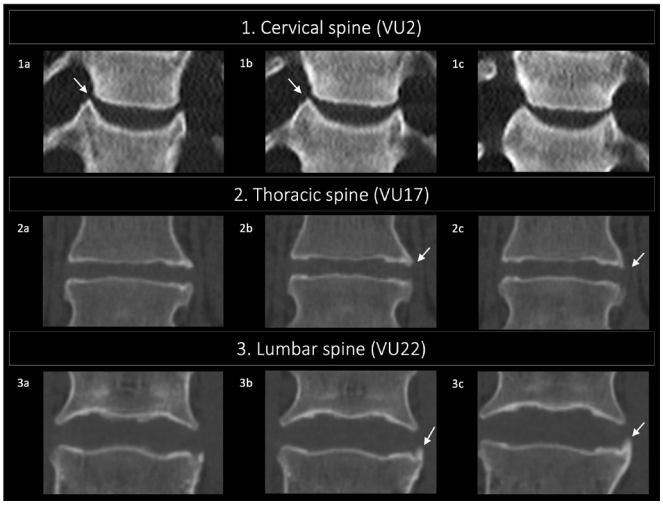

Figure 4 Coronal view of a CT Syndesmophyte Score grade 1 by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c); the syndesmophyte (white arrows) does not reach 50% of the intervertebral disc space. The images 1c, 2a, and 3a, do not depict syndesmophytes. VU, vertebral unit. VU2—lower half of C3 and upper half of C4. VU17—lower half of T11 and upper half of T12. VU22—lower half of L4 and upper half of L5.

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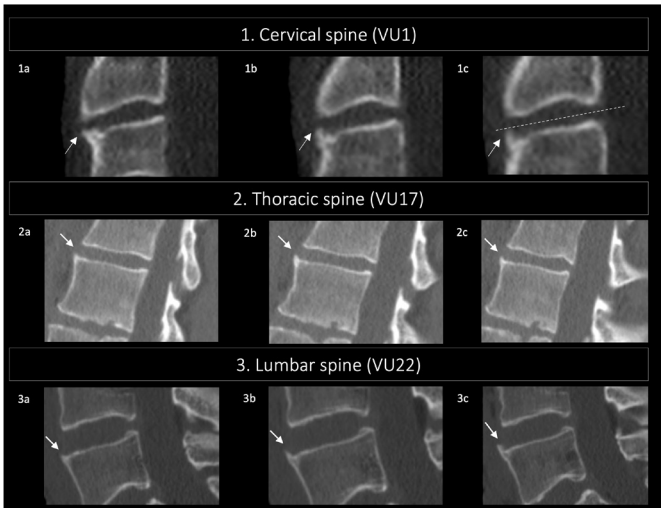

Figure 5 Sagittal view of a CT Syndesmophyte Score grade 1 by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c); the syndesmophyte (white arrows) does not reach 50% of the intervertebral disc space. VU, vertebral unit. VU1—lower half of C2 and upper half of C3. VU17—lower half of T11 and upper half of T12. VU22—lower half of L4 and upper half of L5.

with the normal vertebral corners extending beyond the middle part of the vertebra. Once more, normal vertebral corners should not be confused with syndesmophytes (examples are marked with asterisks in figure 10).

Imaging acquisition

The examples used in the present atlas were obtained from coded low-dose CT images of patients with axSpA included in Leiden as part of the SPondyloArthritis Caught Early study and SIAS study.[7 14] A few images were also obtained from patients with axSpA included

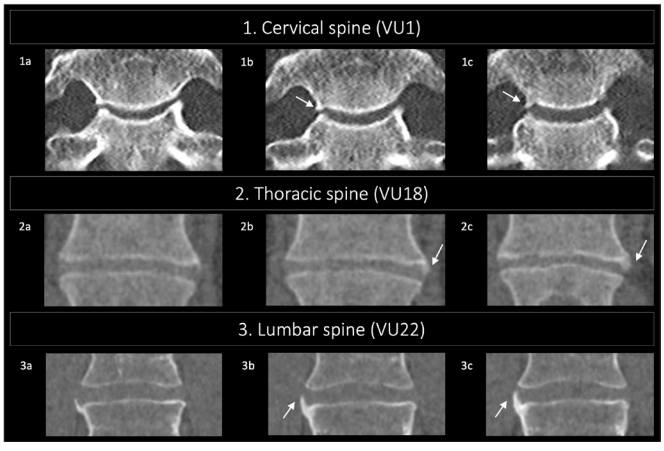

Figure 6 Coronal view of a CT Syndesmophyte Score grade 2 by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c); the syndesmophyte (white arrows) reaches 50% or more of the intervertebral disc space (IDS). In the images 1a, 2a, and 3a, the syndesmophytes have not yet reached 50% or more of the IDS. VU, vertebral unit. VU1—lower half of C2 and upper half of C3. VU18—lower half of T12 and upper half of L1. VU22—lower half of L4 and upper half of L5.

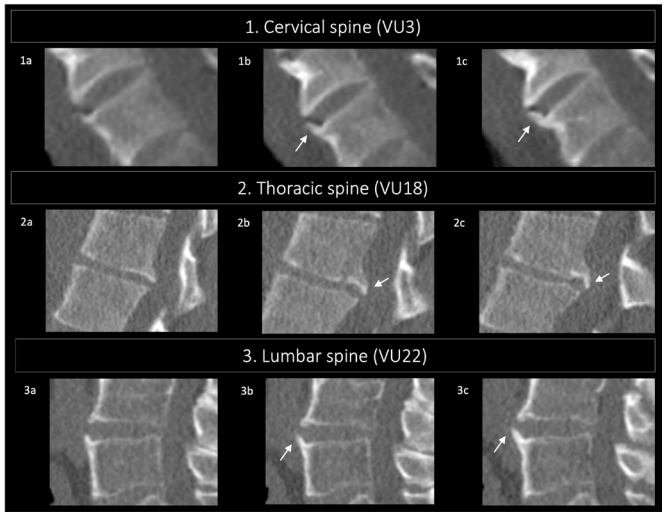

Figure 7 Sagittal view of a CT Syndesmophyte Score grade 2 by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c); the syndesmophyte (white arrows) reaches 50% or more of the intervertebral disc space (IDS). In the images 1a, 2a, and 3a, the syndesmophytes have not yet reached 50% or more of the IDS. VU, vertebral unit. VU3—lower half of C4 and upper half of C5. VU18—lower half of T12 and upper half of L1. VU22—lower half of L4 and upper half of L5.

in the AXspa International OutcoMe Assessment study, an ongoing study (in progress unpublished data). CTs were acquired in different machines from different vendors (online supplemental table 1). Helical CT scans

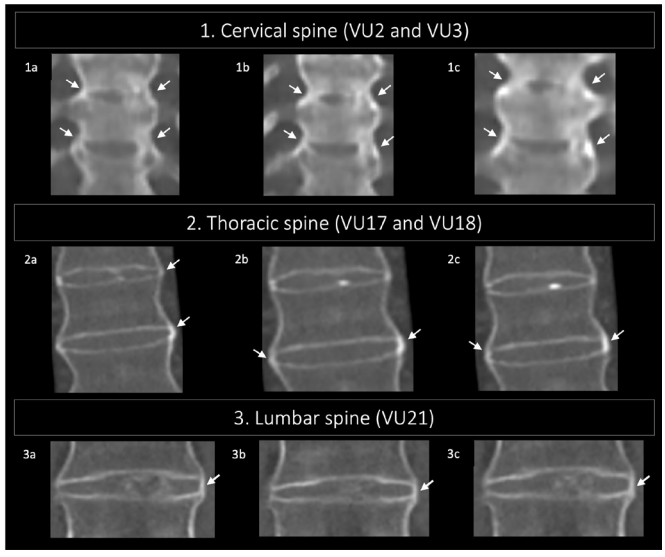

Figure 8 Coronal view of a CT Syndesmophyte Score grade 3 by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c); the syndesmophytes (white arrows) are bridging the intervertebral disc space (IDS). Consequently, a score of 3 is (per definition) reported in both quadrants on opposite sides of the IDS. VU, vertebral unit. VU2—lower half of C3 and upper half of C4. VU3—lower half of C4 and upper half of C5. VU17—lower half of T11 and upper half of T12. VU18—lower half of T12 and upper half of L1. VU21—lower half of L3 and upper half of L4.

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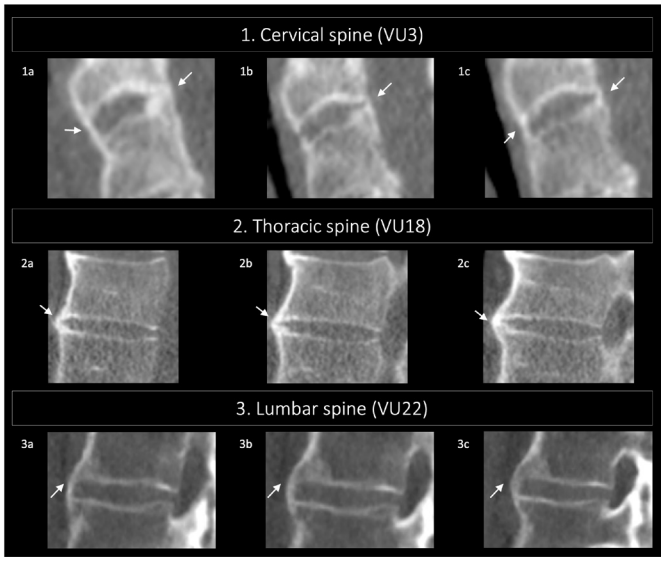

Figure 9 Sagittal view of a CT Syndesmophyte Score grade 3 by spinal segment (cervical: 1a to 1c; thoracic: 2a to 2c; lumbar: 3a to 3c); the syndesmophytes (white arrows) are bridging the intervertebral disc space (IDS). Consequently, a score of 3 is (per definition) reported in both quadrants on opposite sides of the IDS. VU, vertebral unit. VU3—lower half of C4 and upper half of C5. VU18—lower half of T12 and upper half of L1. VU22—lower half of L4 and upper half of L5.

were performed with the patient in supine position and arms up. The entire spine was assessed from the superior endplate of C2 to the inferior endplate of S5 using

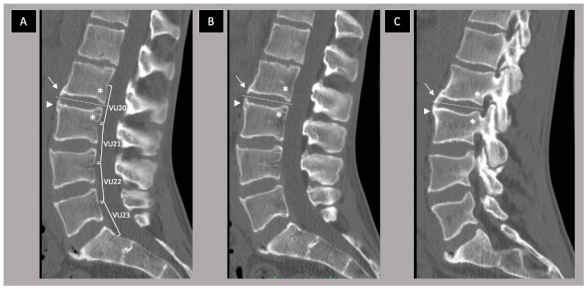

Figure 10 Sagittal view of the lumbar spine from L1 to S1. To identify abnormalities, repetitive scrolling through multiple slices is needed. The reader should be focused on one vertebral unit (VU) at a time, and the highest score should be reported for each quadrant. This example focusses on VU20 (L2–L3). The arrow shows a syndesmophyte at the upper anterior corner (quadrant 1), not reaching 50% of the intervertebral disc space (IDS; grade 1) in A and B. However, on image C, the syndesmophyte reaches over 50% of the IDS, yet not bridging (grade 2). In this example, a grade 2 should be reported for quadrant 1. The arrowhead points to a syndesmophyte in the lower anterior corner (quadrant 4) not reaching 50% of the IDS from A to C. Therefore, a grade 1 should be reported in quadrant 4. No abnormalities are present in quadrants 2 and 3 (posterior quadrants) of VU20 (L2–L3) in which the sloped vertebral corners (asterisks) must not be mistaken as syndesmophytes, and thus a grade 0 should be scored here. The total CTSS score for the VU20 is 2+0+0+1=3.

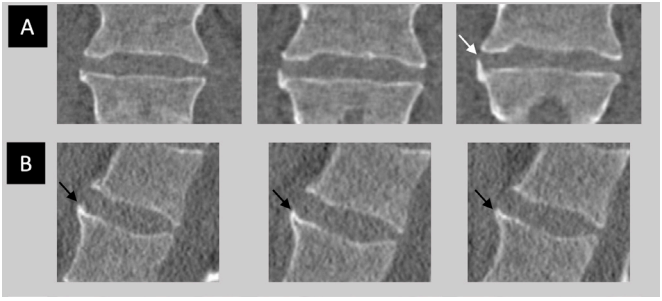

Figure 11 Coronal (A) and sagittal (B) views of the thoracic spine focused on vertebral unit 19 (L1–L2). Syndesmophytes are assessed in both coronal and sagittal planes. Therefore, it is possible that syndesmophytes of different grades are observed in different planes. In this example, a syndesmophyte of grade 2 (white arrow) should be reported in quadrant 3 on the coronal plane (A), while a syndesmophyte of grade 1 (black arrows) should be reported in quadrant 3 on the sagittal plane (B).

predefined settings (online supplemental table 1). Out of primary raw data or volume reconstructions, coronal and sagittal 1.5–3 mm images were generated with a sharp bone kernel by using iterative reconstructions (online supplemental table 2). The estimated radiation exposure for the total spine scan including the sacroiliac joints varied depending on the patients' body size and the scanner system but was invariably ≤4 mSv with an overall (estimated) effective dose of 2.1±1.2 mSv—further details given in the online supplemental table 1.

NOTIFICATIONS AND CHALLENGES

Each CT scan is a 3D reconstruction composed of 2D images. As only one slice of the scan can be viewed at a time, the identification of abnormalities requires repetitive scrolling through multiple slices. The reader should focus on one VU at a time, systematically assessing each VU individually preferably from top to bottom starting cervical (C2) and working their way down to S1. If a transitional vertebra (sixth lumbar vertebra) is present, any abnormalities in that vertebra can be noted separately as a free text comment.

The CTSS was developed to be used in patients with an established diagnosis of axSpA. Therefore, the diagnosis should be known before starting to score. This method focuses on syndesmophytes, and while applying the CTSS, some notifications and typical features are worth considering:

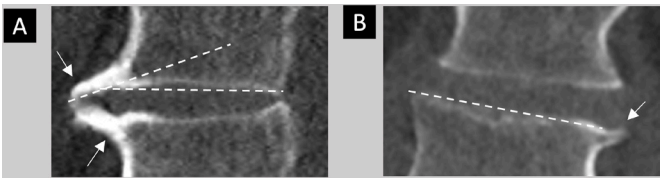

Figure 12 Examples of osteophytes in the coronal (A) and sagittal view (B). The osteophyte is a bone spur that grows horizontally or with an angle measured from the endplate of less than 45°.

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Figure 13 Differential lesion examples in the coronal (A–C) and sagittal (D–E) planes in an HLA-B27 positive 69-year-old male patient with 24 years of inflammatory back pain symptom duration and radiographic axial spondyloarthritis (axSpA). In these representative examples, vertical bony outgrowths typical of syndesmophytes (arrow) are present along with large non-marginal, and horizontal to the endplate lesions, flowing at the anterior longitudinal ligaments, consistent with diffuse idiopathic skeletal hyperostosis (arrowhead). There is a right convex lumbar scoliosis with secondary degenerative changes: disc space loss, irregularity of endplates and (excessive) spondylophyte formation. In addition, there is spondylosis at multiple thoracic levels, with preservation of the intervertebral disc space (IDS). The dashed arrows show an example of a bone spur that initially started horizontally then grows vertically to the endplate; the atypical orientation together with the coexistence of degenerative changes of the endplate and IDS imposes caution in the classification of this structure as a syndesmophyte indicative of axSpA. These images mark the necessity to view all slices in two planes together with clinical findings such as age and disease duration (if available) in order not to misinterpret degeneration for axSpA.

1. The syndesmophyte consists of a bony spur, in principle, originating from the vertebral corner (figures 4–11).
2. Syndesmophytes are classically vertically directed bony outgrowth lesions. These lesions contrast with horizontally directed extensions from the endplates, osteophytes/spondylophytes, which are seen in spondylosis and degenerative disc disease (DDD).[15] A growth angle of ≥45° measured from the endplate is currently regarded as a surrogate to distinguish syndesmophytes from osteophytes.[16] An easy approach is drawing a straight line parallel to and extending from the vertebral endplate; the syndesmophyte typically crosses this line upright to the opposite vertebra (figure 12). In the cervical spine, due to the concave or convex anatomy of the vertebral endplate (images 1a to 1c of figure 2), some adaptations of this method are necessary. First, the reader should compare one quadrant to the others within the same VU (eg, Q1 VU2 vs Q2 VU2, Q3 VU2 and Q4 VU2), followed by the comparison to a corresponding quadrant from another VU (eg, Q1 VU2 vs Q1 VU3), while considering the typical shape of the (cervical) vertebra and the natural variation among individual patients.
3. To be considered of grade 1 or higher, the syndesmophyte should cross the drawn straight line extending from the vertebral endplate (figure 4; third image can be scored as grade 1).
4. The IDS can be preserved in axSpA. However, IDS changes, such as IDS height loss or fissures, can also be observed as occurring in DDD, particularly with ageing.[15] In the presence of such IDS alterations, the reader needs to be cautious with assessing syndesmophytes. In fact, exuberant bone formation due to degenerative changes might mimic syndesmophyte growth (figure 13).[15] Also, in DDD, osteophytes can be difficult to differentiate from axSpA new bone formation, even if applying the ≥45° angle method explained in point 2 (figure 13). VUs with degenerative spondylophytes should be assigned a zero in the syndesmophyte grading. Occasionally, readers may find lesions compatible with syndesmophytes due to axSpA in vertebrae with reduced IDS height. In those circumstances, grades 1–3 should be attributed to syndesmophytes using the height of the IDS as it stands. Clinical information (eg, age, disease duration), if available, can assist in inter-

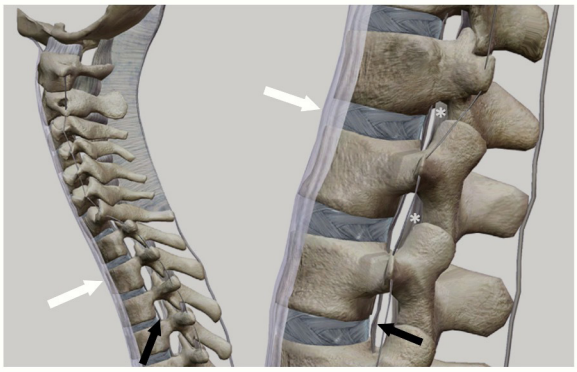

Figure 14 Anatomy of the spinal ligaments adjacent to the vertebral bodies. Adapted from Reijnierse.[15] Sagittal view from occiput to T4 (left image) and a detail of T1 to T3 (right image). It shows the anterior longitudinal ligament (white arrows), posterior longitudinal ligament (black arrows), and the ligamentum flavum (white asterisk).

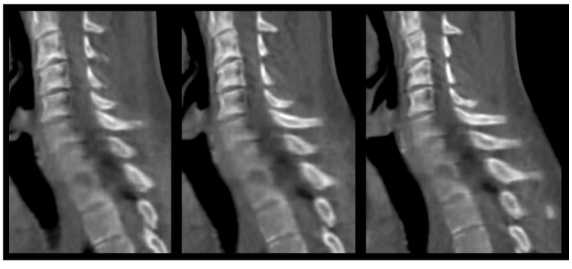

Figure 15 Sagittal view of photon starvation phenomenon and beam hardening from C6 to T1. Streak artefacts and dark bands cause a significant impairment of the imaging quality at the shoulder girdle's level.

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preting images avoiding misclassification of degeneration as axSpA.

5. Differentiation between primary ossified ligaments and bony outgrowths of the vertebral endplate might be challenging.[15] However, the anatomy references, namely the site of attachment of the ligaments, can be of help (figure 14). Lesions clearly corresponding to ossified ligaments (eg, without a clear spur coming from the vertebral corner) must be excluded from the scoring according to the CTSS.
6. Readers should be aware of differential lesions since these lesions cannot be scored as part of the CTSS, a method specifically developed for axSpA-related syndesmophytes. Some examples include osteophytes, parasyndesmophytes or non-marginal syndesmophytes (originating from the lateral part of the vertebra), spondylosis or diffuse idiopathic skeletal hyperostosis (figures 12 and 13). Providing extensive information about these differential lesions is beyond the scope of this atlas. Main differences described for other imaging modalities, for example, conventional radiographs, also apply here and were previously reported.[15]

Subsequently, we describe other particularities and challenges readers may face when using the CTSS. One quadrant can display several grades in different slices. In figure 10, the upper corner syndesmophyte (white arrow) should be judged as grade 1 on the first two slices (A and B) but grade 2 on the following slice (C). The reader should report the highest grade; in the example, this is grade 2.

As mentioned above, syndesmophytes are assessed in both coronal and sagittal planes. By doing this, it is possible to assess a syndesmophyte in one plane while not visible, and therefore not assessed, in the other. Moreover, it is plausible that the grade given in a certain VU differs in sagittal and coronal planes (figure 11).

Depending on the CT manufacturer, radiation dose and reconstruction algorithms, some artefacts or poor imaging quality may be present.[17–19] In these circumstances, the reader should avoid scoring a syndesmophyte if questionable or not clearly seen. figure 15 shows a paradigmatic example in which VUs can be difficult to assess because of streak artefacts.[17 18] Modern algorithms with iterative AI-based reconstructions can reduce these artefacts.[13 19 20] To accurately assess the CTSS, it is essential to guarantee equal imaging quality over the whole spine while ensuring low radiation exposure.[20] Therefore, all measures for improving the image quality (eg, modern reconstruction techniques) and reducing the radiation exposure (eg, special filters) should be applied. The presence of artefacts or other concerns in using the CTSS scoring can be added as comment to the scoring sheet.

In summary, this atlas provides comprehensive guidance on how to use the CTSS when assessing syndesmophytes on (low-dose) CTs in patients with the diagnosis of axSpA. The reference images were carefully selected aiming at assisting the decisions of any reader (irrespective of experience) when scoring syndesmophytes according to the CTSS method.

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