

Body Imaging

Relevance of spinal lesions in chronic non-bacterial osteomyelitis and imaging features on whole body MRI

Savvas Andronikou^{a,b}, Addressa Guariento^a, Antrea Zouvanni^c, Carlos Yaya^a,
Linda Tebogo Hlabangana^{d,*}

^a Department of Radiology, Children's Hospital of Philadelphia, Philadelphia, PA, United States of America

^b Perelman School of Medicine, University of Pennsylvania, United States of America

^c University Hospitals Sussex NHS Foundation trust, 7 Fleet Street, BN1 4HD, United Kingdom of Great Britain and Northern Ireland

^d University of the Witwatersrand, Radiology Department, School of Clinical Medicine, Faculty of Health Sciences, Johannesburg, South Africa

ARTICLE INFO

Keywords:

Chronic non-bacterial osteomyelitis
Chronic recurrent multifocal osteomyelitis
Spine
Vertebra
Whole-body-MRI

ABSTRACT

Chronic non-bacterial osteomyelitis (CNO) is an autoinflammatory bone disorder that usually involves long bone metaphyses of the lower extremities and can affect the clavicles, pelvis, mandible, sternum, and spine. The spine is recognized as a classic feature of CNO, but routine whole-body MRI with coronal-only STIR images may underreport its frequency. Dedicated sagittal spinal imaging is important not only in proving a multifocal process but also because vertebral height loss and vertebra plana in CNO can result in scoliosis and kyphosis. Aggressive treatment can prevent vertebral collapse and promote vertebral body height recovery. Spinal CNO typically involves the thoracic spine, is often multifocal, usually shows non-contiguous vertebral involvement, and demonstrates abnormal high T2W signal at the vertebral body and endplate destruction—sometimes as a spondylodiscitis. Importantly, in distinguishing it from other potential causes, CNO usually has no soft tissue mass. Treatment with pamidronate may result in a bone-in-bone appearance.

1. Introduction

Chronic non-bacterial osteomyelitis (CNO)^{1,2} is an autoinflammatory bone disorder affecting primarily children and adolescents, with mean disease onset around 10 years of age.^{3–7} The term ‘chronic recurrent multifocal osteomyelitis’ (CRMO) has been used as an alternative to describe this entity; however, CNO is an umbrella term that also captures presentations that are neither multifocal nor recurrent.¹ Bone involvement is usually metaphyseal in the long bones of the lower extremities but is also seen in the clavicles, pelvis, mandible, sternum and spine.^{3,8}

Although initially considered rare, spinal vertebral involvement has more recently been considered a classic feature of CNO.⁹ It is more common in girls,^{4,10} with a prevalence ranging from 16 % to 37 %, ^{4,6–8,11–13} and affects up to 60 % of patients with the monogenic type of CNO.¹⁴ The majority of patients with spine involvement in sporadic CNO are associated with a pauci-focal pattern of disease as described by Andronikou et al.⁸ It is also likely that the frequency of spinal involvement in CNO is underestimated because whole-body MRI (WBMRI) is

traditionally performed in the coronal plane, which is less ideal than the sagittal plane for imaging the vertebral column.

Spine involvement can appear during the course of the disease or be the presenting feature at onset. The clinical presentation is usually with inflammatory pain and ‘stiffness’ of the spine.⁶ Even though bone pain can be especially severe and incapacitating with spinal involvement,¹⁵ vertebral lesions can also remain silent and children can present with a vertebral deformity after an asymptomatic course.^{4,6,12,16,17} Spinal lesions may also be detected incidentally during WBMRI performed for pain elsewhere.

This narrative review aims to highlight the relevance of detecting spinal lesions in CNO and summarize their MR imaging features.

2. The relevance of spinal disease in CNO

Awareness of spinal disease in CNO is relevant for two reasons:

Firstly, CNO needs to be considered in the differential diagnosis of unifocal (Fig. 1a) and multifocal (Fig. 1b) vertebral lesions, solitary vertebra plana (Fig. 1c), and spondylodiscitis (Fig. 1d) when detected

* Corresponding author at: Department of Radiology, School of Clinical Medicine, University of the Witwatersrand, 7 York Road, Parktown, 2193 Johannesburg, Gauteng Province, South Africa.

E-mail addresses: yayac@chop.edu (C. Yaya), LT.Hlabangana@gmail.com (L.T. Hlabangana).

<https://doi.org/10.1016/j.clinimag.2025.110564>

Received 20 April 2025; Received in revised form 4 July 2025; Accepted 17 July 2025

Available online 24 July 2025

0899-7071/© 2025 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

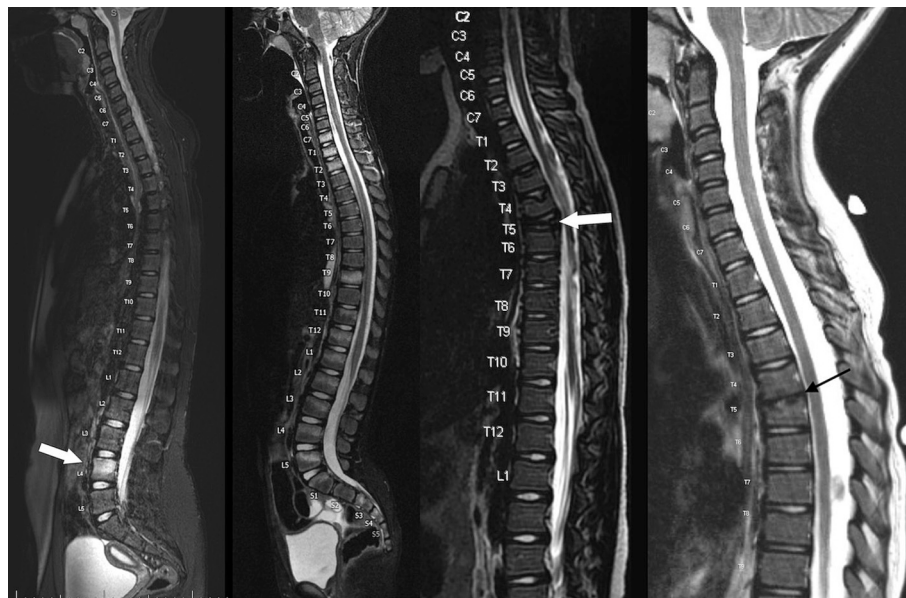


Fig. 1. a-d: Unifocal and multifocal vertebral patterns of involvement in chronic non-bacterial osteomyelitis (CNO). (a) Sagittal STIR sequence from a whole-body MRI in an 8-year-old girl demonstrates a single abnormal high-signal lesion centered in the upper part of the L4 vertebral body. (b) Sagittal STIR sequence from a whole-body MRI in a 6.5-year-old girl demonstrating multifocal vertebral CNO lesions (C7-T2; T9-T11-L5, S1 and S3). (c) Sagittal T2-weighted MRI of the spine demonstrates vertebra plana at T5 with associated mild kyphosis in an 8-year-old girl with multifocal contiguous spinal CNO—also affecting T4 with mild height loss. (d) Sagittal T2 weighted imaging of the spine in an 8-year-old girl with CNO demonstrates loss of height of T5 with superior endplate irregularity and adjacent loss of height and signal in the T4/5 disc (arrow), resulting in very mild kyphotic deformity.

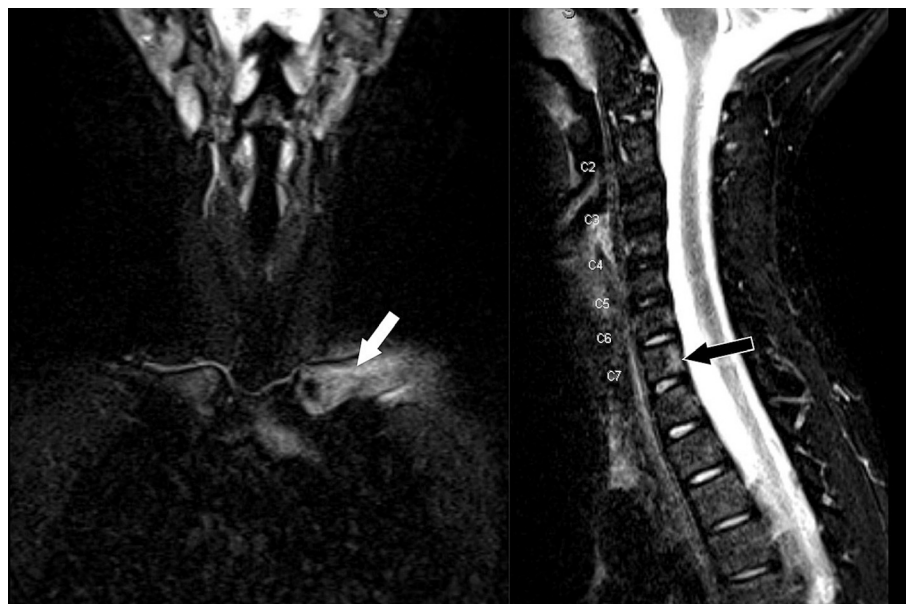


Fig. 2. a and b: MRI in an 8-year-old girl with suspected chronic non-bacterial osteomyelitis (CNO). (a) Upper thoracic initial coronal STIR MRI demonstrates high signal and mild expansion of the left clavicle representing a presumed single detected lesion. (b) Purposeful addition of sagittal STIR MRI demonstrates an additional lesion in the posterior aspect of the C7 vertebral body (not appreciated on the coronal sequences). Even though clavicular lesions are highly specific for CNO in children, the second lesion supports the diagnosis by demonstrating a multifocal disease. In addition, the detection of a spinal lesion would trigger initiation of more aggressive therapy for CNO.

on imaging in a child. Narrowing the differential diagnosis further requires that radiologists be familiar with any characteristic or distinguishing features of CNO as compared to other causes of spondylitis and spondylodiscitis.

Secondly, the purposeful search and identification of spinal lesions in patients with known or suspected CNO is important because [a] these can convert diagnostic considerations from a unifocal to a multifocal process (Fig. 2), [b] they may be the only lesions with characteristic

CNO features, and [c] spinal disease can result in significant complications and poor outcomes.¹⁸

Complications include the loss of vertebral integrity with resultant kyphosis¹⁵ and/or scoliosis^{4,16,19,20} (Fig. 3c), all of which can be asymptomatic.^{3,14} Although these complications can lead to long-standing problems,¹⁵ resolution of deformities and total recovery of vertebral height can in some cases be accomplished with aggressive treatment with bisphosphonates.⁴ For example, Gleeson et al found a

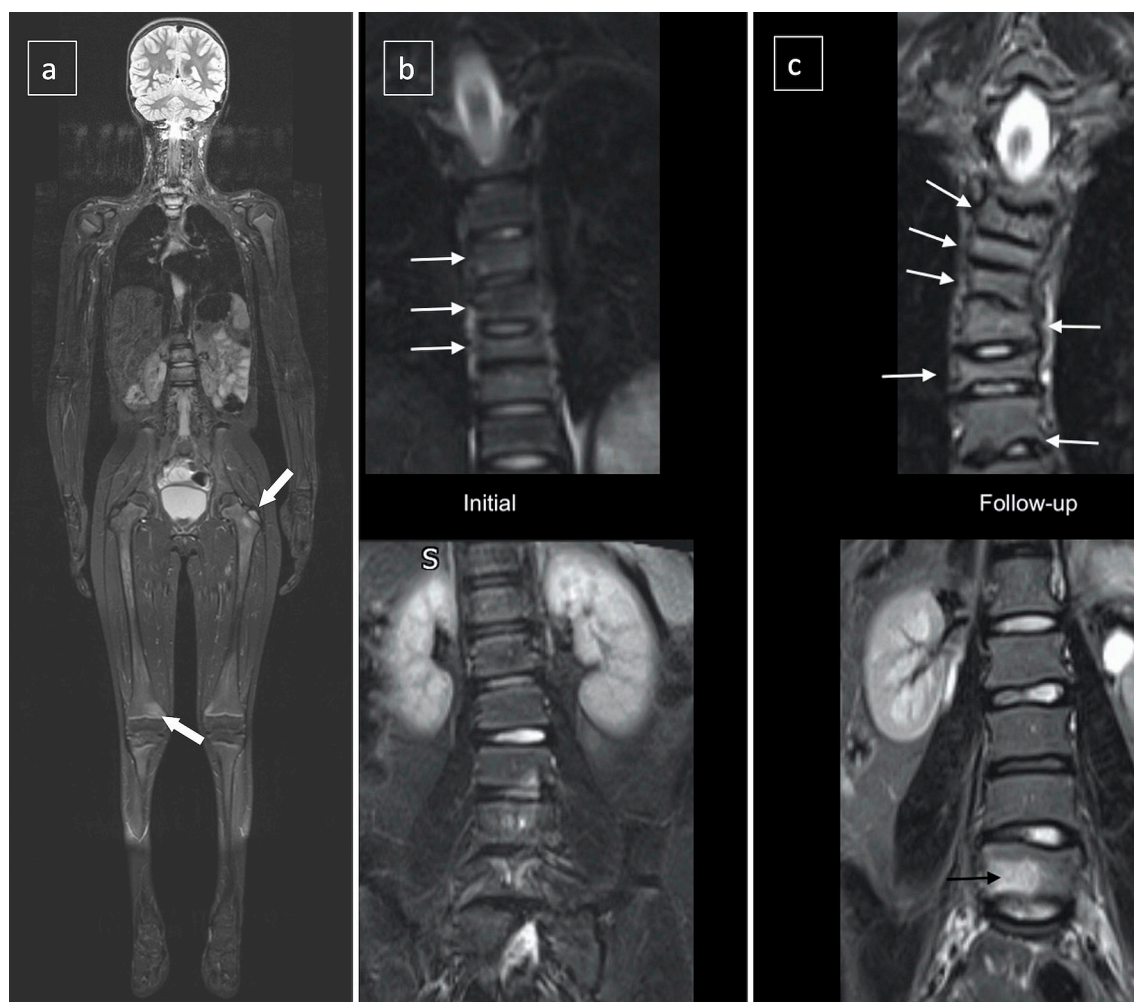


Fig. 3. a - c: Coronal plane STIR whole-body MRI in two different children with chronic non-bacterial osteomyelitis (CNO). Composed/'stitched' coronal STIR MRI (a) in a 6-year-old girl demonstrates multiple high signal abnormality at the distal femoral metaphyses and around the left greater trochanter (arrows). Coronal STIR MR imaging in a different 6-year-old girl at presentation (b) and follow-up (c) demonstrates an increased number of vertebral bodies involved as well as progressed vertebral height loss (white arrows) in the thoracic spine (upper row) and an additional new high-signal lesion in the lumbar spine (lower row) (black arrow) with resultant scoliosis. Worsening kyphosis over time makes the coronal imaging less ideal for demonstrating the vertebral bodies.



Fig. 4. a - c: Sagittal and parasagittal STIR MRI of the thoracic and lumbosacral spine in a child with chronic non-bacterial osteomyelitis (CNO) demonstrates typical multifocal spinal involvement of CNO, predominantly involving non-contiguous thoracic (T6, T10, T11 and lumbar (L1, L2, L4) vertebral bodies in the superior or inferior sub-endplate regions. There is also extension of signal abnormality to involve the posterior elements at the pedicle of T10 (arrow in b). No soft tissue mass is demonstrated.



Fig. 5. a and b: MRI of the lumbosacral spine in a child with chronic non-bacterial osteomyelitis (CNO) showing spondylodiscitis. Sagittal (a) and coronal (b) STIR MRI demonstrate a spondylodiscitis pattern of involvement of contiguous vertebra L5 and S1, which demonstrate abnormal signal, with irregularity of the inferior L5 endplate and superior S1 endplate as well as height loss of the intervening disc (arrows). There is no associated soft tissue mass or tissue edema.

significant improvement in vertebral shape in two of three cases with multiple vertebrae affected and an improvement in the kyphotic angle after pamidronate treatment.⁵ Silva et al found that all their patients had total (45 %) or partial (55 %) improvement of spinal inflammation after aggressive treatment; however, recurrence was observed in 27 %.²⁰ Therefore, identification of spine involvement should dictate a more aggressive treatment approach^{14,21,22} not only for patients with deformity but for all patients with vertebral CNO lesions as a preventative measure. There are, however, reports in the literature where there is failure to regain vertebral height and where deformities are permanent after a long follow-up, especially in patients who did not receive bisphosphonate treatment.^{4,6} Early detection of spinal lesions should therefore be a priority for WBMRI in CNO, which should be modified to demonstrate the spine optimally.²³ Recognition of the importance of spinal involvement is reflected in its inclusion as a distinct parameter of proposed scoring systems for CNO (RINBO; CROMRIS; RAI-CROMRIS).^{11,19,24}

3. Imaging in spinal CNO

The goals of diagnostic imaging in CNO are primarily to avoid diagnostic biopsy by narrowing the differential diagnosis.⁹ Research has shown that retrospective application of the Bristol or Jansson criteria

could decrease bone biopsies by at least 80 %. However, biopsy is recommended in all cases of single-site CNO, except for those involving the medial clavicle. Biopsy should also be considered in cases where there is only spinal involvement in children below the age of 5 years. In patients with suspected multi-focal CNO, biopsy should be performed only when the diagnosis is uncertain.²⁵

CNO has some characteristic patterns of distribution of multifocal disease as well as typical individual lesion imaging features that can assist in making a diagnosis.^{3,8} Even though X-rays can demonstrate lytic lesions (in the early phase of the disease), sclerosis and hyperostosis (later in the disease), vertebral end-plate irregularity/notching,⁶ and compression fractures/vertebra plana and kyphosis, these often fail to demonstrate a distinct lesion in the spine for making a final diagnosis.^{22,26,27} A normal X-ray also does not exclude CNO⁹; Falip et al found that 55 % of their patients with spinal involvement had normal X-rays.⁶ MRI, in particular WBMRI, is the modality of choice for evaluating patients with suspected or confirmed CNO. MRI detects skeletal lesions better than clinical examination¹⁹ and allows detection of asymptomatic lesions which, when multifocal, can provide the basis for narrowing the differential diagnosis. WBMRI is designed for coverage and speed for detecting multiple lesions.²⁸ WBMRI protocols usually consist of coronal short-tau inversion recovery (STIR) (Fig. 3) of the entire body including all extremities, without contrast.^{21,23,24} In CNO, this needs to ensure



Fig. 6. a and b: Progression of chronic non-bacterial osteomyelitis (CNO) with developing kyphosis. Sagittal STIR MRI at initial presentation (a) and follow-up (b) is ideal for demonstrating the progression of spinal CNO lesions (white arrows) with worsening vertebral height loss, development of multiple vertebra plana, additional vertebral body and posterior element lesions, as well as progressive kyphosis. The contiguous vertebral involvement in this patient is not typical for CNO.

detection of spinal lesions; therefore, sagittal STIR images of the spine have recently been recommended to be performed routinely. This is because of the increased awareness of spinal lesions in CNO and because coronal images are perceived to be less sensitive for detecting spinal lesions (Fig. 3 b and c), including any resultant vertebral height loss and kyphosis.^{3,6,28} Some MRI protocols prefer a turbo inversion recovery magnitude (TIRM) sequence instead of STIR, with the whole body acquired in coronal and sagittal planes. TIRM is very sensitive in detecting early edema of the bone marrow in early osteomyelitis.²⁹ Additionally, T1-weighted sequences are useful to characterize findings seen on the fluid sensitive sequences and distinguish these from normal hematopoietic marrow in the pelvis and spine.³⁰ During initial patient evaluation, T1 imaging with contrast is also helpful in differentiating CNO lesions from infection and tumors.²⁵ Initial imaging can be expanded to add more detailed imaging of any areas of interest for making a definitive diagnosis, especially for locations such as the spine, hands, and feet.

Most cases of spinal CNO involve the thoracic spine,^{8,17,20,24,31} followed by the lumbo-sacral and less commonly the cervical spine.^{4,26} Even though involvement of the spine is often multifocal, it is reportedly unusual to have two contiguous vertebral bodies involved (Fig. 4).^{5,6,8} However, Guariento et al found that 17 % of their population had some contiguous spondylodiscitis pattern, making the differential diagnosis with infectious spondylodiscitis more challenging. It is important to highlight that the majority of those patients had a mixed pattern where both continuous and non-continuous involvement were present.¹⁷

There are minor discrepancies in the literature about the distribution of abnormal signal within the vertebral body. Some authors report that

the abnormal signal is usually located at the anterior vertebral body,²⁴ while others have described the superior and the posterior vertebral body as the most affected area. Moreover, in a study by Guariento et al 35 % of cases the vertebral edema pattern diffuse.¹⁷ Posterior elements, pedicles, lamina, facets, and spinous processes can be affected (Fig. 4),²⁴ but in the majority, the posterior element edema is continuous with the vertebral body edema.¹⁷ Only in rare cases are the posterior elements the sole region of spinal involvement.^{17,20} Spinal CNO lesions predominantly demonstrate lytic destruction with erosion of the vertebral endplates, ranging in frequency from 57 to 73 % of cases^{17,20} (Fig. 5). This location is considered the equivalent of the peri-physeal and metaphyseal portion of long bones.³² Subchondral sclerosis and adjacent bone marrow changes displaying decreased T1W signal and some degree of increased T2W signal can also be seen.²⁶ The low T1W signal of CNO is important for differentiating lesions from normal red marrow which shows an intermediate T1W signal, despite both having a moderately high signal on STIR.^{15,23,24} When vertebral collapse occurs, the MRI signal can be variable.⁶ Diffusion-weighted imaging (DWI) can also be used,²⁴ showing a high ADC value within the lesions.³³ This may be useful to differentiate CNO from malignancy, but further validation of this feature is necessary.^{23,34}

Spinal lesions have previously also been described as being spondylodiscitis-like (Fig. 5) (i.e., discitis above or below the involved vertebra with decreased water content in the nucleus pulposus), leading to a decrease in the T2W signal.^{8,26,32} Typically, however, disease does not cross the disc which helps differentiate CNO from infectious causes.^{6,23,35} Most importantly, in distinguishing CNO spinal lesions from

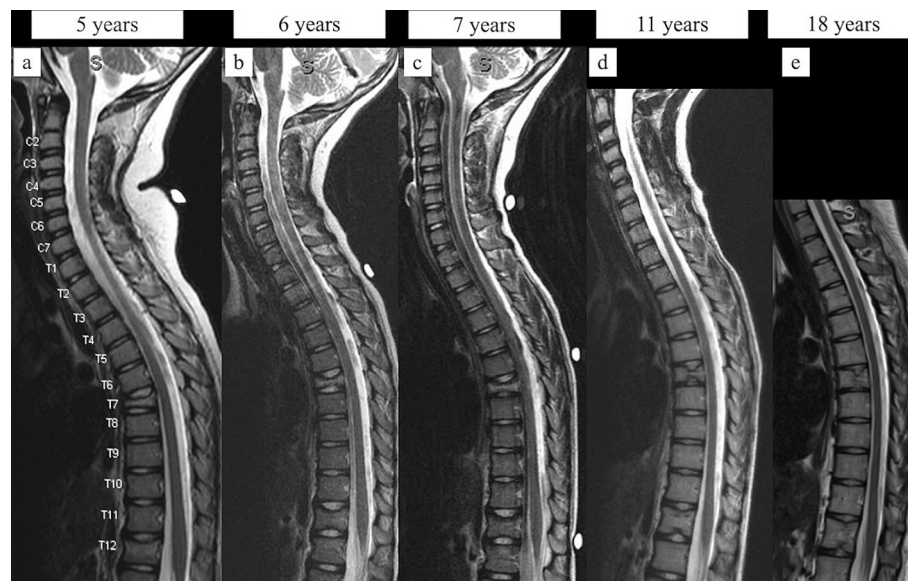


Fig. 7. (a-e): Natural history of chronic non-bacterial osteomyelitis (CNO) spinal lesions demonstrating height recovery of vertebra plana. Sagittal T2-weighted MRI from presentation at 5 years of age (a) and for over 13 years until age 18 years (b-e) in a girl with a history of recurrent back pain, associated with recurrent bone pain in other sites of the body. Sagittal T2W MRI of the spine demonstrates multifocal vertebral involvement, initially with vertebra plana at T7 and some superior height loss of T12. Follow-up at 6 years of age and 7 years of age demonstrates the vertebra plana at T7 and progressive height loss of the T12 vertebral body. Follow-up sagittal T2W at 11 years and most recent follow-up sagittal T2W at 18 years of age demonstrate the recovery of vertebral body height of the T7 and T12 vertebra, though not entirely normal morphologically, without use of pamidronate (bisphosphonate) therapy.

infection (including tuberculosis) and malignancy, CNO usually does not demonstrate a soft tissue mass.^{23,26} When soft tissue changes are found, they are often mild. However, it has been shown that lesions which demonstrate excessive bone growth may demonstrate significant soft tissue components which may be mistaken for tumor-related soft tissue masses.²⁵ A range of frequencies has been reported for increased signal of the soft tissues on STIR, from being ‘rare’ to seen in up to 45 % of cases.^{3,17,20} This may reflect differences in methodology among studies when analyzing soft tissue inflammation.

3.1. Complications

Vertebral fracture can result in height loss and even vertebra plana (Fig. 6).^{3,14} Vertebral height loss and resultant complications—such as kyphosis and scoliosis—can all be present at the spinal disease recognition¹⁷ or develop during the course of known disease. In the cohort of Jansson et al, almost half of patients with vertebral fracture developed scoliosis,¹² and Hospach et al found that 22 % of their CNO study population had scoliosis or kyphosis.⁴

3.2. Evolution and treatment-related imaging findings

The high signal intensity of CNO lesions on STIR images is often seen to regress concomitantly with the resolution of pain, and gradually there is a return to normal fatty marrow signal intensity.^{20,26} Follow-up MRI is recommended to be performed at 3, 6, and 12 months, which can also inform the aggressiveness of treatment approach,² followed by 6 monthly scans thereafter. This is where the main power of WBMRI lies as the optimal diagnostic tool in disease follow-up after CNO diagnosis (Fig. 7).

On early imaging after bisphosphonate treatment, T2W and STIR may be unremarkable, while T1W shows a mild hyperintensity of the epiphyseal plates. Later, the equivalent of “zebra lines” in the long bones, corresponding to layers of sclerosed non-decalcified cartilage at the metaphysis, results in a “bone-in-bone” appearance at the vertebral bodies, i.e., a double contour (Fig. 8).^{36,37}

4. Differential diagnosis of spinal CNO

The differential diagnosis of spinal lesions in children is discussed according to distribution below.

4.1. Single spinal lytic lesions including vertebra plana

These can be due to Ewing sarcoma (peak age 15 years), but an extra-osseous mass accompanies these lesions at disease presentation.^{32,38} Langerhans cell histiocytosis (LCH) is typically the main cause of vertebra plana, typically in younger children. Other causes of vertebra plana include acute lymphoblastic leukemia, other neoplasms, and infection.^{38,39} However, unlike CNO, the soft tissue is altered in ≥ 50 % of cases.^{32,38,40–43}

4.2. Multifocal vertebral lesions

Leukemia usually shows a diffuse pattern of involvement in the spine, while lymphoma can cause focal, patchy, or diffuse vertebral lesions.^{44,45} Both demonstrate bone marrow replacement with a sharp transition between normal and abnormal marrow, which differs from the bone marrow edema in CNO. However, superimposed fractures and collapse can also occur, with leukemia and lymphoma leading to acute bone edema indistinguishable from CNO.⁴⁵ Spinal metastases in children are usually secondary to neuroblastoma (younger children) and may be accompanied by a soft tissue mass³² with spinal canal involvement, not seen in CNO.⁴⁶

4.3. Spondylodiscitis and contiguous vertebral involvement

Tuberculous (TB) spondylitis most often affects the lower thoracic and lumbar spine.^{47,48} It mainly involves the vertebral bodies and disc destruction, with contiguous involvement of multiple vertebrae later in the disease.²³ On MRI, TB is shown to involve the anterior vertebral body and demonstrates low T1 and high T2 signal in the endplates like CNO. However, it demonstrates a typical paraspinous and/or epidural soft tissue mass/abscesses and subligamentous spread across multiple

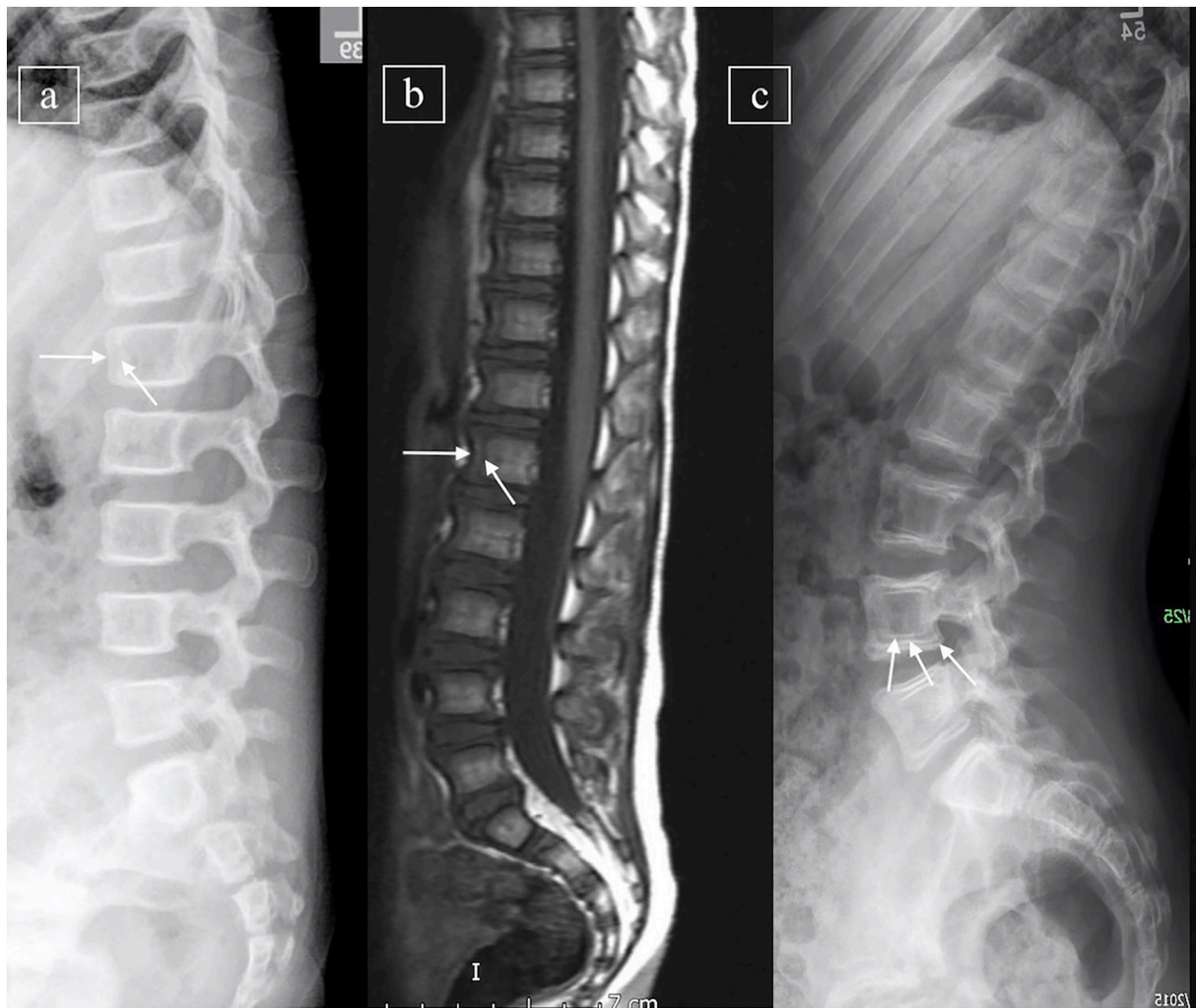


Fig. 8. a-c: Lumbo-sacral spine imaging after bisphosphonate treatment for chronic non-bacterial osteomyelitis (CNO) demonstrating a “bone-in-bone” appearance of the vertebral bodies, i.e., a double contour (arrows) on plain X-ray (a) and sagittal T1W MRI (b). Follow-up imaging after multiple bisphosphonate doses has resulted in a “multiple-bone-in-bone” appearance (arrows) on plain radiograph (c), which is the equivalent of zebra lines at the metaphyses of long bones.

vertebral segments, which are not features of CNO.^{41,48,49} Pyogenic spondylitis typically affects the lumbar spine as contiguous vertebral body disease with disc involvement.⁵⁰ Irregularities and destruction of the end plates with low T1W and high T2W signal are similar to CNO, but the epidural extension deep to the posterior longitudinal ligament as well as paraspinal inflammation of the soft tissue or fluid collections distinguish pyogenic spondylitis from CNO.^{30,38} Osseous involvement in deficiency of interleukin-1 receptor antagonist (DIRA) presents as recurrent osteomyelitis with osteolytic lesions, which can involve the spine and lead to spinal cord compression and cervical vertebral fusion.^{51,52}

4.4. Multifocal vertebral height loss

Idiopathic osteoporosis, or more commonly in children, osteoporosis secondary to prolonged glucocorticoid treatment, can cause multiple vertebral fractures at multiple levels. Much like CNO lesions, these can be asymptomatic.^{38,53} Hypophosphatasia is a monogenic inborn defect of bone metabolism that leads to defective bone mineralization and has MRI appearances similar to sporadic CNO.^{54,55} Scheuermann disease is the most common cause of kyphotic deformity in adolescents, but it typically affects three or more consecutive thoracic vertebrae with disc degeneration, and even though marrow signal is normal, it can mirror advanced CNO of the spine on MRI.^{32,56,57}

4.5. Pitfalls

Residual red marrow or red marrow reconversion, due to an increased hematopoietic demand occurring initially in the axial skeleton, is demonstrated on MRI as multifocal high signal on STIR but shows intermediate signal on T1W (not lower than muscle signal).^{41,45} Therefore, differentiating spinal CNO lesions from marrow reconversion requires that a T1W weighted sequence be performed, where CNO will demonstrate a low T1W signal.^{41,45,58}

5. Conclusion

The frequency of spinal lesions in CNO is likely underestimated due to routine WBMRI being performed largely only in the coronal plane. The addition of sagittal STIR imaging of the spine as a routine sequence is recommended for suspected CNO, with the appreciation that spinal lesions probably occur in more than one-third of children with sporadic CNO. A diagnosis of CNO should be considered in instances of unifocal and multifocal vertebral lesions, vertebra plana, and spondylodiscitis detected on MRI in children. In patients with suspected CNO, the purposeful search of a spinal lesion using WBMRI is important because when detected in association with a lesion in another skeletal site, the differential diagnosis would change to that of a multifocal disease and increase the likelihood of CNO. In addition, because spinal lesions can

cause significant complications and poor outcomes, these warrant more aggressive treatment that can result in recovery.

Spinal CNO may be unifocal or multifocal and usually involves the vertebral bodies, but it can also involve the posterior elements, typically in the region of the endplates, with sparing of the disc. Less commonly, CNO can cause a spondylodiscitis with contiguous vertebral involvement. Lesions are typically of low T1 and high T2 signal intensity but do not typically demonstrate an associated soft tissue mass, differentiating CNO from neoplastic and infective disease. Importantly, vertebral height loss and development of vertebra plana are complications of spinal CNO, but vertebral body height can be regained, and some deformities can be reversed with aggressive management.

CRediT authorship contribution statement

Savvas Andronikou: Writing – review & editing, Writing – original draft, Supervision, Project administration, Formal analysis, Data curation, Conceptualization. **Andressa Guariento:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Antrea Zouvanni:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Carlos Yaya:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Linda Tebogo Hlabangana:** Writing – review & editing, Writing – original draft, Project administration, Formal analysis.

Declaration of Generative AI and AI-assisted technologies in the writing process

Not applicable.

Funding

This research was by the principal investigator. No additional funding was obtained.

Declaration of competing interest

The authors declare that they have no competing interests.

References

- Ben-Chetrit E, Gattorno M, Gul A, et al. Consensus proposal for taxonomy and definition of the autoinflammatory diseases (AIDs): a Delphi study. *Ann Rheum Dis* 2018 Nov;77(11):1558–65.
- Beck C, Morbach H, Beer M, et al. Chronic nonbacterial osteomyelitis in childhood: prospective follow-up during the first year of anti-inflammatory treatment. *Arthritis Res Ther* 2010;12(2):R74.
- von Kalle T, Heim N, Hospach T, Langendörfer M, Winkler P, Stuber T. Typical patterns of bone involvement in whole-body MRI of patients with chronic recurrent multifocal osteomyelitis (CRMO). *Rofo* 2013 Jul;185(7):655–61.
- Hospach T, Langendoerfer M, von Kalle T, Maier J, Dannecker GE. Spinal involvement in chronic recurrent multifocal osteomyelitis (CRMO) in childhood and effect of pamidronate. *Eur J Pediatr* 2010 Sep;169(9):1105–11.
- Gleeson H, Wiltshire E, Briody J, et al. Childhood chronic recurrent multifocal osteomyelitis: pamidronate therapy decreases pain and improves vertebral shape. *J Rheumatol* 2008 Apr;35(4):707–12.
- Falip C, Alison M, Boutry N, et al. Chronic recurrent multifocal osteomyelitis (CRMO): a longitudinal case series review. *Pediatr Radiol* 2013 Mar;43(3):355–75.
- Girschick H, Finetti M, Orlando F, et al. The multifaceted presentation of chronic recurrent multifocal osteomyelitis: a series of 486 cases from the Eurofever international registry. *Rheumatology (Oxford)* 2018 Aug 1;57(8):1504.
- Andronikou S, Mendes da Costa T, Hussien M, Ramanan AV. Radiological diagnosis of chronic recurrent multifocal osteomyelitis using whole-body MRI-based lesion distribution patterns. *Clin Radiol* 2019 Sep;74(9):737.e3–737.e15.
- Zhao DY, McCann L, Hahn G, Hedrich CM. Chronic nonbacterial osteomyelitis (CNO) and chronic recurrent multifocal osteomyelitis (CRMO). *J Transl Autoimmun* 2021 Mar;20(4):100095.
- d'Angelo P, de Horatio LT, Toma P, et al. Chronic nonbacterial osteomyelitis - clinical and magnetic resonance imaging features. *Pediatr Radiol* 2021;51(2):282–8.
- Capponi M, Pires Marafon D, Rivoecchi F, et al. Assessment of disease activity using a whole-body MRI derived radiological activity index in chronic nonbacterial osteomyelitis. *Pediatr Rheumatol Online J* 2021 Aug 14;19(1):123.
- Jansson A, Renner ED, Ramser J, et al. Classification of non-bacterial osteitis: retrospective study of clinical, immunological and genetic aspects in 89 patients. *Rheumatology (Oxford)* 2007 Jan;46(1):154–60.
- Ma L, Liu H, Tang H, et al. Clinical characteristics and outcomes of chronic nonbacterial osteomyelitis in children: a multicenter case series. *Pediatr Rheumatol Online J* 2022 Jan 3;20(1):1.
- Kubaszewski L, Wojdasiewicz P, Rożek M, et al. Syndromes with chronic non-bacterial osteomyelitis in the spine. *Reumatologia* 2015;53(6):328–36.
- Schaal MC, Gendler L, Ammann B, et al. Imaging in non-bacterial osteomyelitis in children and adolescents: diagnosis, differential diagnosis and follow-up—an educational review based on a literature survey and own clinical experiences. *Insights Imaging* 2021 Aug 9;12(1):113.
- Voit AM, Arnoldi AP, Douis H, et al. Whole-body magnetic resonance imaging in chronic recurrent multifocal osteomyelitis: clinical Longterm assessment may underestimate activity. *J Rheumatol* 2015 Aug;42(8):1455–62.
- Guariento A, Sharma P, Andronikou S. MRI features of spinal chronic recurrent multifocal osteomyelitis/chronic non-bacterial osteomyelitis in children. *Pediatr Radiol* 2023 Sep;53(10):2092–103.
- Kaut S, Van den Wyngaert I, Christiaens D, et al. Chronic nonbacterial osteomyelitis in children: a multicentre Belgian cohort of 30 children. *Pediatr Rheumatol Online J* 2022 Jun 13;20(1):41.
- Arnoldi AP, Schlett CL, Douis H, et al. Whole-body MRI in patients with non-bacterial osteitis: radiological findings and correlation with clinical data. *Eur Radiol* 2017 Jun;27(6):2391–9.
- Silva JS, Bettencourt S, Madureira I, Conde M, Conceição C. Chronic nonbacterial osteomyelitis in neuroradiology - behavior and evolution of vertebral and mandibular lesions on imaging. *Pediatr Radiol* 2024 Nov;54(12):2046–59.
- Zhao Y, Chauvin NA, Jaramillo D, Burnham JM. Aggressive therapy reduces disease activity without skeletal damage progression in chronic nonbacterial osteomyelitis. *J Rheumatol* 2015 Jul;42(7):1245–51.
- Zhao Y, Ferguson PJ. Chronic nonbacterial osteomyelitis and chronic recurrent multifocal osteomyelitis in children. *Pediatr Clin N Am* 2018 Aug;65(4):783–800.
- Andronikou S, Kraft JK, Offiah AC, et al. Whole-body MRI in the diagnosis of paediatric CNO/CRMO. *Rheumatology (Oxford)* 2020 Oct 1;59(10):2671–80.
- Zhao Y, Sato TS, Nielsen SM, et al. Development of a scoring tool for chronic nonbacterial osteomyelitis magnetic resonance imaging and evaluation of its interrater reliability. *J Rheumatol* 2020 May 1;47(5):739–47.
- Sheikh Z, Bhatt D, Chowdhury M, Johnson K. Challenges in the imaging and diagnosis of chronic non-bacterial osteomyelitis (CNO). *Clin Radiol* 2025 Jun;85:106905.
- Jurik AG, Egund N. MRI in chronic recurrent multifocal osteomyelitis. *Skeletal Radiol* 1997 Apr;26(4):230–8.
- Roderick MR, Shah R, Rogers V, Finn A, Ramanan AV. Chronic recurrent multifocal osteomyelitis (CRMO) - advancing the diagnosis. *Pediatr Rheumatol Online J* 2016 Aug 30;14(1):47.
- Darge K, Jaramillo D, Siegel MJ. Whole-body MRI in children: current status and future applications. *Eur J Radiol* 2008 Nov;68(2):289–98.
- Hauer MP, Uhl M, Allmann KH, Laubenberger J, Zimmerhackl LB, Langer M. Comparison of turbo inversion recovery magnitude (TIRM) with T2-weighted turbo spin-echo and T1-weighted spin-echo MR imaging in the early diagnosis of acute osteomyelitis in children. *Pediatr Radiol* 1998 Nov;28(11):846–50.
- Caranci F, Tedeschi E, Ugga L, et al. Magnetic resonance imaging correlates of benign and malignant alterations of the spinal bone marrow. *Acta Biomed* 2018 Jan 19;89(1–S):18–33.
- Menashe SJ, Iyer RS, Ngo A-V, Rosenwasser NL, Zhao Y, Maloney E. Whole-body MRI at initial presentation of pediatric chronic recurrent multifocal osteomyelitis and correlation with clinical assessment. *Pediatr Radiol* 2022 Nov;52(12):2377–87.
- Shah A, Rosenkranz M, Thapa M. Review of spinal involvement in chronic recurrent multifocal osteomyelitis (CRMO): what radiologists need to know about CRMO and its imitators. *Clin Imaging* 2022 Jun;86:1.
- Leclair N, Thörmer G, Sorge I, Ritter L, Schuster V, Hirsch FW. Whole-body diffusion-weighted imaging in chronic recurrent multifocal osteomyelitis in children. *PLoS One* 2016 Jan 22;11(1):e0147523.
- Unable to find information for 12380430.
- Unable to find information for 12380445.
- Papakonstantinou O, Sakalidou M, Atsali E, Bizimi V, Mendrinou M, Alexopoulou E. Radiographic and MR imaging findings of the spine after bisphosphonate treatment, in a child with idiopathic juvenile osteoporosis. *Case Rep Radiol* 2015 Jan 20;2015:727510.
- Loizidou A, Andronikou S, Burren CP. Pamidronate “zebra lines”: a treatment timeline. *Radiol Case Rep* 2017 Dec;12(4):850–3.
- Hirji H, Saifuddin A. Paediatric acquired pathological vertebral collapse. *Skeletal Radiol* 2014 Apr;43(4):423–36.
- Baky F, Milbrandt TA, Arndt C, Houdek MT, Larson AN. Vertebra plana in children may result from etiologies other than eosinophilic granuloma. *Clin Orthop Relat Res* 2020 Oct;478(10):2367–74.
- Xu X, Han S, Jiang L, et al. Clinical features and treatment outcomes of Langerhans cell histiocytosis of the spine. *Spine J* 2018 Oct;18(10):1755–62.
- Sato TS, Watal P, Ferguson PJ. Imaging mimics of chronic recurrent multifocal osteomyelitis: avoiding pitfalls in a diagnosis of exclusion. *Pediatr Radiol* 2020 Jan 4;50(1):124–36.
- Demaerel P, Van Gool S. Paediatric neuroradiological aspects of Langerhans cell histiocytosis. *Neuroradiology* 2008 Jan;50(1):85–92.
- Peng X-S, Pan T, Chen L-Y, Huang G, Wang J. Langerhans' cell histiocytosis of the spine in children with soft tissue extension and chemotherapy. *Int Orthop* 2009 Jun;33(3):731–6.

- 44 Nguyen JC, Davis KW, Arkader A, et al. Pre-treatment MRI of leukaemia and lymphoma in children: are there differences in marrow replacement patterns on T1-weighted images? *Eur Radiol* 2021 Oct;31(10):7992–8000.
- 45 Chan BY, Gill KG, Rebsamen SL, Nguyen JC. MR imaging of pediatric bone marrow. *Radiographics* 2016 Oct;36(6):1911–30.
- 46 Trahair T, Sorrentino S, Russell SJ, et al. Spinal canal involvement in neuroblastoma. *J Pediatr* 2017 Sep;188:294–8.
- 47 Yao Y, Song W, Wang K, et al. Features of 921 patients with spinal tuberculosis: a 16-year investigation of a general hospital in Southwest China. *Orthopedics* 2017 Nov 1; 40(6):e1017–23.
- 48 Andronikou S, Bindapersad M, Govender N, et al. Musculoskeletal tuberculosis - imaging using low-end and advanced modalities for developing and developed countries. *Acta Radiol* 2011 May 1;52(4):430–41.
- 49 Andronikou S, Jadwat S, Douis H. Patterns of disease on MRI in 53 children with tuberculous spondylitis and the role of gadolinium. *Pediatr Radiol* 2002 Nov;32(11): 798–805.
- 50 Taxter AJ, Chauvin NA, Weiss PF. Diagnosis and treatment of low back pain in the pediatric population. *Phys Sportsmed* 2014 Feb;42(1):94–104.
- 51 Alsharief AN, Laxer RM, Wang Q, et al. Monogenic autoinflammatory diseases in children: single center experience with clinical, genetic, and imaging review. *Insights Imaging* 2020 Jul 31;11(1):87.
- 52 Jesus AA, Goldbach-Mansky R. IL-1 blockade in autoinflammatory syndromes. *Annu Rev Med* 2014;65:223–44.
- 53 Lentle B, Koromani F, Brown JP, et al. The radiology of osteoporotic vertebral fractures revisited. *J Bone Miner Res* 2019 Mar;34(3):409–18.
- 54 Morbach H, Hedrich CM, Beer M, Girschick HJ. Autoinflammatory bone disorders. *Clin Immunol* 2013 Jun;147(3):185–96.
- 55 Beck C, Morbach H, Wirth C, Beer M, Girschick HJ. Whole-body MRI in the childhood form of hypophosphatasia. *Rheumatol Int* 2011 Oct;31(10):1315–20.
- 56 Gokce E, Beyhan M. Radiological imaging findings of Scheuermann disease. *World J Radiol* 2016 Nov 28;8(11):895–901.
- 57 Liu N, Guo X, Chen Z, et al. Radiological signs of Scheuermann disease and low back pain: retrospective categorization of 188 hospital staff members with 6-year follow-up. *Spine* 2014 Sep 15;39(20):1666–75.
- 58 Patel MD, Brian J, Chauvin NA. Pearls and pitfalls in imaging bone marrow in pediatric patients. *Semin Ultrasound CT MR* 2020 Oct;41(5):472–87.