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Charles H. Bush
Vicki Kalen

Three-dimensional computed tomography in the assessment of congenital scoliosis

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C.H. Bush, M.D. (✉)
Department of Radiology,
University of Florida College of Medicine,
1600 SW Archer Road, Box 100374,
Gainesville, FL 32610, USA

V. Kalen, M.D.
Department of Orthopedics,
University of Florida College of Medicine,
Gainesville, FL 32610, USA

Present address:
V. Kalen, 210 Holly Road,
Edgewater, MD 21037, USA

Abstract *Objective*. Patients with congenital vertebral anomalies frequently are afflicted with kyphoscoliosis, with the curvatures often being severe and progressive. Spinal fusion almost always is the treatment of choice in such patients. This report examines the use of three-dimensional computed tomography (3D CT) in the preoperative investigation of patients with congenital scoliosis.
Design and patients. Twelve spinal CT examinations on 11 pediatric patients with congenital scoliosis underwent image processing to produce 3D images. The 3D images were compared with both the axial sections from the CT examinations and multiplanar reformations with regard to the detection of malformations liable to cause progression of scoliosis (i. e., hemivertebrae and unsegmented bars).
Results and conclusions. In six of the 12 cases, the 3D images provided improved depiction of the congenital anomalies and their interrelationships compared with planar CT images. This work suggests that 3D CT can be a useful tool in the assessment of patients with congenital scoliosis.

Key words Scoliosis · Computed tomography · Three-dimensional imaging · Spinal anomalies · Spine surgery

Introduction

Congenital scoliosis is defined as lateral spinal curvature secondary to congenital anomalies of vertebrae and their supporting structures. It was first recognized by Winter et. al. [1] that scoliosis secondary to certain asymmetric congenital vertebral malformations can have a serious prognosis, resulting in what are often rigid, progressive spinal curvatures that are a difficult management problem for orthopedists compared with idiopathic or neuromuscular spinal curvatures [2]. In patients with progressive congenital scoliosis, conservative treatment is almost never successful, and surgical fusion is the accepted treatment. The goal of fusion is to stop further progression of the curve, as the deformity in such patients is rarely, if ever, amenable to full surgical correction.

The vertebral malformations in congenital scoliosis can be classified as segmentation defects and formation defects. Segmentation defects can be eccentric or symmetric. Eccentric defects take the form of unsegmented bars, which are solid bars of bone fusing the disc spaces and apophyseal joints of two or more vertebral segments on one side of the spine, leaving the other side unaffected. Asymmetric unsegmented bars can be anterolateral, traversing the intervertebral disc between two contiguous vertebral bodies, or posterior, such as pedicle bars. Unsegmented bars have a high correlation with progressive spinal curvatures. Symmetric defects lead to block vertebrae, which do not by themselves lead to progressive curvatures. Formation defects are those anomalies in which one or more of the embryologic precursors of a vertebra is anomalous or absent. Formation defects include hemivertebrae, cleft vertebrae, and derangements of the neural arch which lead to spina bifida. Frequently associated neurologic abnormalities in patients with neural arch formation defects, such as in patients with dia-

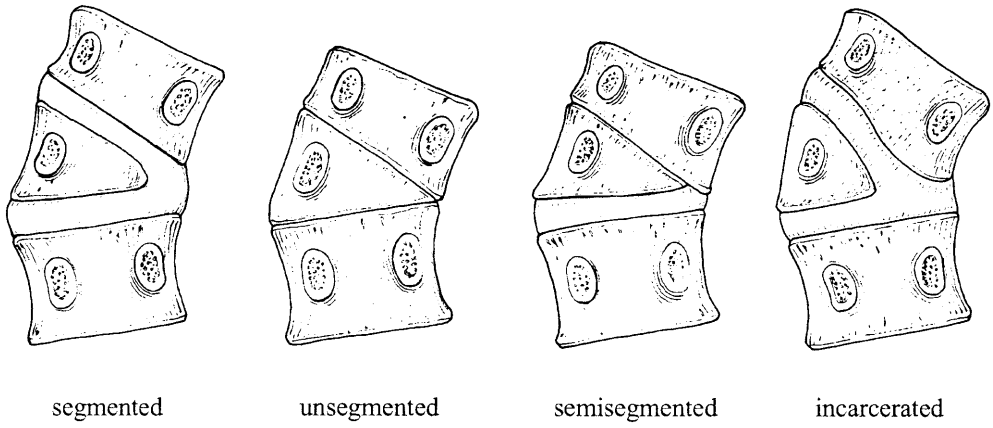

Fig. 1 The four classes of hemivertebrae. Due to the presence of an open intervertebral disc on both sides of the anomaly, segmented and incarcerated hemivertebrae have the greatest potential to cause progressive spinal curvatures

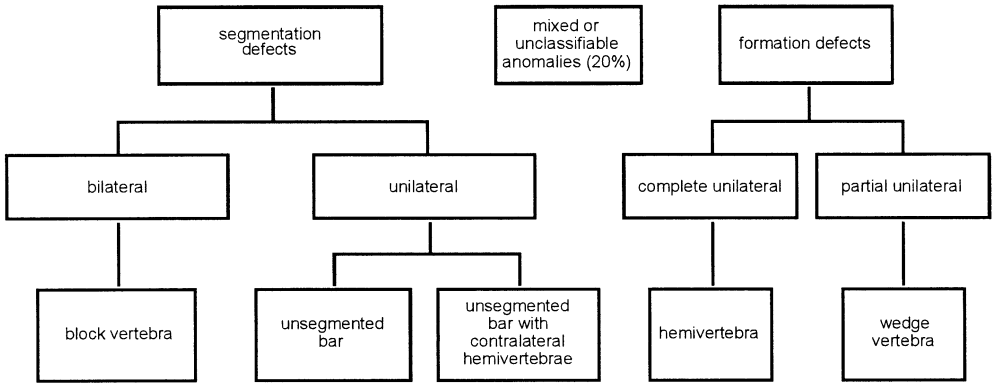

Fig. 2 Classification scheme of anomalies in congenital scoliosis. (Adapted with permission from McMaster [3], p. 228)

stematomyelia and spinal dysraphism, complicate the management of congenital scoliosis. Four different types of hemivertebrae are recognized, differing in their potential to cause progressive spinal curvatures (Fig. 1). Approximately 20% of the anomalies causing congenital kyphoscoliosis are complex or unclassifiable (Fig. 2) [3].

Prompt detection of patients with congenital spinal malformations is crucial in identifying candidates for surgery, as those with anomalies known to have a high potential for causing progressive curvatures are best served by early fusion. Estimation of the potential for curve progression in such patients requires the clinician to identify both the specific anomalies and their interrelationship. Although radiography alone will often suffice to define the anomalies in patients with congenital spinal malformations, especially in younger patients, adequate radiologic evaluation of more complex congenital spinal curvatures has traditionally required either tomography or computed tomography with multiplanar image reformation. However, the complex three-dimensional nature of many vertebral malformations makes their characterization by planar cross-sectional imaging methods difficult. Based on the usefulness of three-dimensional computed tomography (3D CT) in the evaluation of other abnormalities in the spine [4–6], we have employed this modality in the assessment of the vertebral malformations in pediatric patients with congenital scoliosis.

Subjects and methods

Eleven patients with scoliosis in whom radiographs showed that the curvature appeared to be secondary to congenital vertebral anomalies were chosen for this study. These patients all had radiographs deemed insufficient for definitive evaluation of their anomalies by one of the authors, an experienced pediatric orthopedic surgeon. The patients ranged in age from 10 months to 14 years. One of the patients had anomalies in two separate regions of the spine, which were imaged with two noncontiguous sets of axial CT sections during the same session, producing two separate image data sets for 3D reconstruction. Sedation with oral chloral hydrate was administered in accordance with the pediatric conscious sedation protocol of our institution about 1 h before imaging to uncooperative patients in our series, as well as those under 3 years of age.

A GE HighLight Advantage (Milwaukee, Wis.) CT scanner was used exclusively. As helical CT became available during the course of our study, this technique was utilized for only two of the patients in our series. The examinations were all performed without intravenous contrast, and used section thicknesses of 1 mm or 3 mm spaced every 1 mm or 2 mm respectively (9 patients) or helical 1 mm or 3 mm scanning (2 patients). A targeted field of view centered over the spine was used, with 120–140 kV, 200–340 mA, and 1– 2 s scan times. Raw data from the examinations were reconstructed in a soft tissue algorithm to optimize the quality of the 3D images. The axial images from the examinations were also reconstructed in a high-frequency, edge-enhancing bone algorithm, and were used to produce sagittal and coronal reformatted images. An ISG Allegro workstation (ISG Technologies, Toronto, Ontario) was used to generate the 3D images using density threshold seeding. As any voxels on the axial images over the threshold density were in-

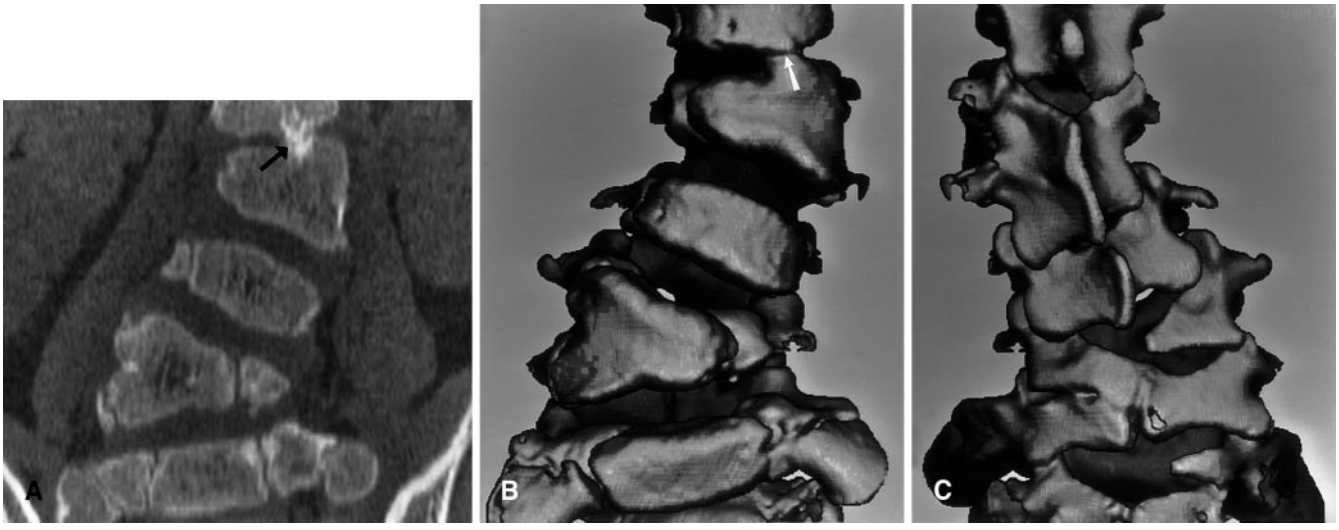

Fig. 3A–C A 3-year-old boy with a congenital left lumbar scoliosis. A coronal reformatted image from his CT examination (**A**) and 3D CT images (**B, C**) both depict upper and lower lumbar hemivertebrae, as well as an upper lumbar bar (*arrow*)

cluded in the 3D reconstruction, portions of ribs or iliac wings included on the field of view of the axial image also appeared on the 3D images, which often obscured the spinal anomalies. Thus, when relevant, manual exclusion of extraspinal bony structures by the operator from each of the axial CT images used for 3D reconstruction allowed 3D image generation with these structures subtracted out. The 3D images were routinely obtained at increments of 15° or 30° of rotation about the longitudinal axis of the spine.

The examinations were reviewed by one of the coauthors, an experienced musculoskeletal radiologist, in two sessions. As the 3D image processing was often time-intensive, this task was usually performed at the end of the work day. Thus, the axial images were initially reviewed on an ISG VRS 800 workstation (ISG Technologies, Toronto, Ontario) having the ability to produce multiplanar reformations, and the results were recorded. Current conventional scoliosis radiographs were available at this time on all patients. Then, the examination was again reviewed on the following work day on the same workstation with the 3D images made available on film. The results were again recorded, with particular attention to findings seen on the 3D image set that were not visualized or visualized only in retrospect on the axial and reformatted CT images.

Results

Three patients underwent imaging of thoracic vertebral anomalies, three patients had thoracolumbar anomalies, and six patients had anomalies in the lumbar spine. Not including the time needed for patient assessment and sedation if necessary, the total examination time for all patients was under 10 min. As the patients ranged in age from infants to teenagers, the effective radiation dosages from the examinations were variable. As a representative example, a 1-year-old infant undergoing examination of the entire lumbar spine from the thoracolumbar junction to the sacrum, a scan length roughly equal to a CT examination of the abdomen, would receive an estimated effective dose of 6.4 mSv by our protocol when extrapolating from the method of Huda et al [7]. This dose can be compared with an estimated effective dose of 0.2 mSv for a conventional two-projection radiographic examination of the lumbar spine in the same infant [8].

In five patients, the spinal anomalies consisted of one or more hemivertebrae. Two patients had hemivertebrae with an unsegmented bar, while two patients had wedge vertebrae, in which a portion of the anomalous segment was hypoplastic, but present. Three patients had complex, unclassifiable anomalies, and the last patient had agenesis of a lumbar segment. All but one of the 3D examinations were of excellent diagnostic quality, with the one suboptimal examination in a 12-year-old boy showing upper thoracic vertebral morphology degraded by artifactual dropout of areas of bony cortex on the 3D images. This artifact was caused by beam hardening produced by the shoulders, which interfered with image thresholding.

In six of the examinations, CT with multiplanar reformations and 3D CT were seen to depict the vertebral anomalies equally well (Fig. 3). In two examinations, 3D CT depicted the anomalies in superior fashion to CT with multiplanar reformations, in that the 3D images provided easier comprehension of the anomalous segments and their relationship with other vertebrae (Fig. 4). In the remaining four cases, 3D CT was markedly superior to CT with multiplanar reformations in displaying the pathology, in that the pathology revealed by the 3D images was difficult to comprehend on both the axial CT sections and the reformatted images even in retrospect (Fig. 5). Three of the four patients in whom 3D CT was markedly superior to CT with multiplanar reformations in displaying the pathology had complex anomalies which involved multiple levels.

Discussion

Successful clinical management of congenital scoliosis frequently requires surgical intervention, as these curves

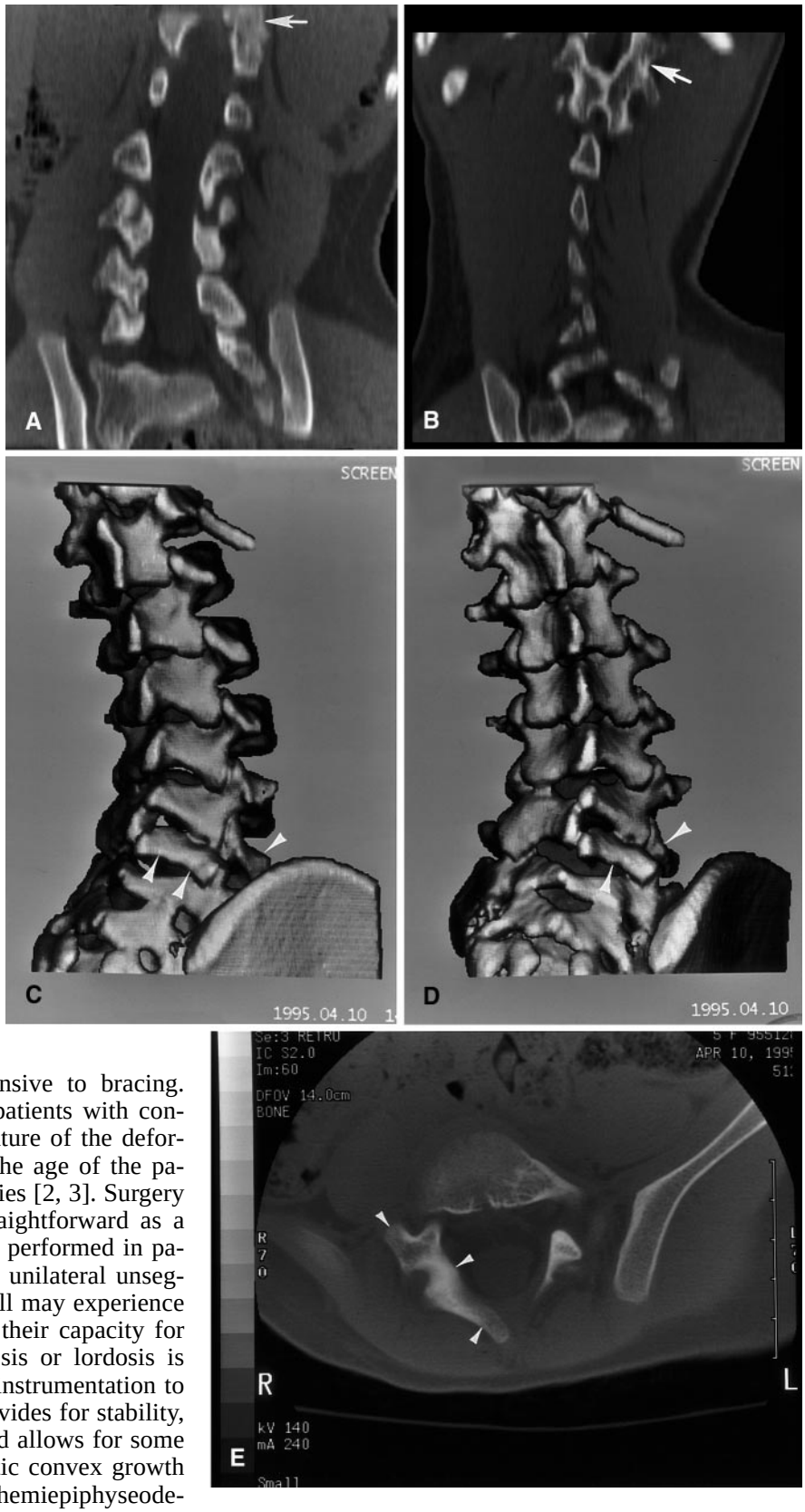

Abb. 4A–E A 5-year-old girl presented for imaging with right lumbar and left thoracolumbar curves. Representative coronal reformatted CT images depict a semisegmented hemivertebra at the thoracolumbar junction, with fusion of the posterior elements (*arrow*) (**A, B**). An unsuspected anomalous segment consisting of only a fragment of the neural arch of a vertebra at the lumbosacral junction is only easy to perceive on the 3D images (**C, D**) (*arrowheads*). Even in retrospective review of reformatted images on a workstation, the lumbosacral junction anomaly was difficult to characterize, and is likewise seen only in retrospect (*arrowheads*) on an axial CT section (**E**). Such segments can cause significant progressive listing of the lumbar spine toward the contralateral side, and are often treated by excision and fusion

often prove progressive and unresponsive to bracing. The choice of surgical treatment for patients with congenital scoliosis should address the nature of the deformity, its location, its natural history, the age of the patient, and the presence of other anomalies [2, 3]. Surgery for congenital scoliosis can be as straightforward as a posterior fusion in situ, which is often performed in patients with single anomalies such as a unilateral unsegmented bar. However, such patients still may experience progression of their deformity due to their capacity for anterior growth, particularly if kyphosis or lordosis is also present. The addition of metallic instrumentation to a posterior fusion in older children provides for stability, reduces the rate of pseudoarthrosis, and allows for some degree of curve correction. Prophylactic convex growth arrest (anterior and posterior convex hemiepiphyseodesis) is a more rigorous two-stage procedure for patients

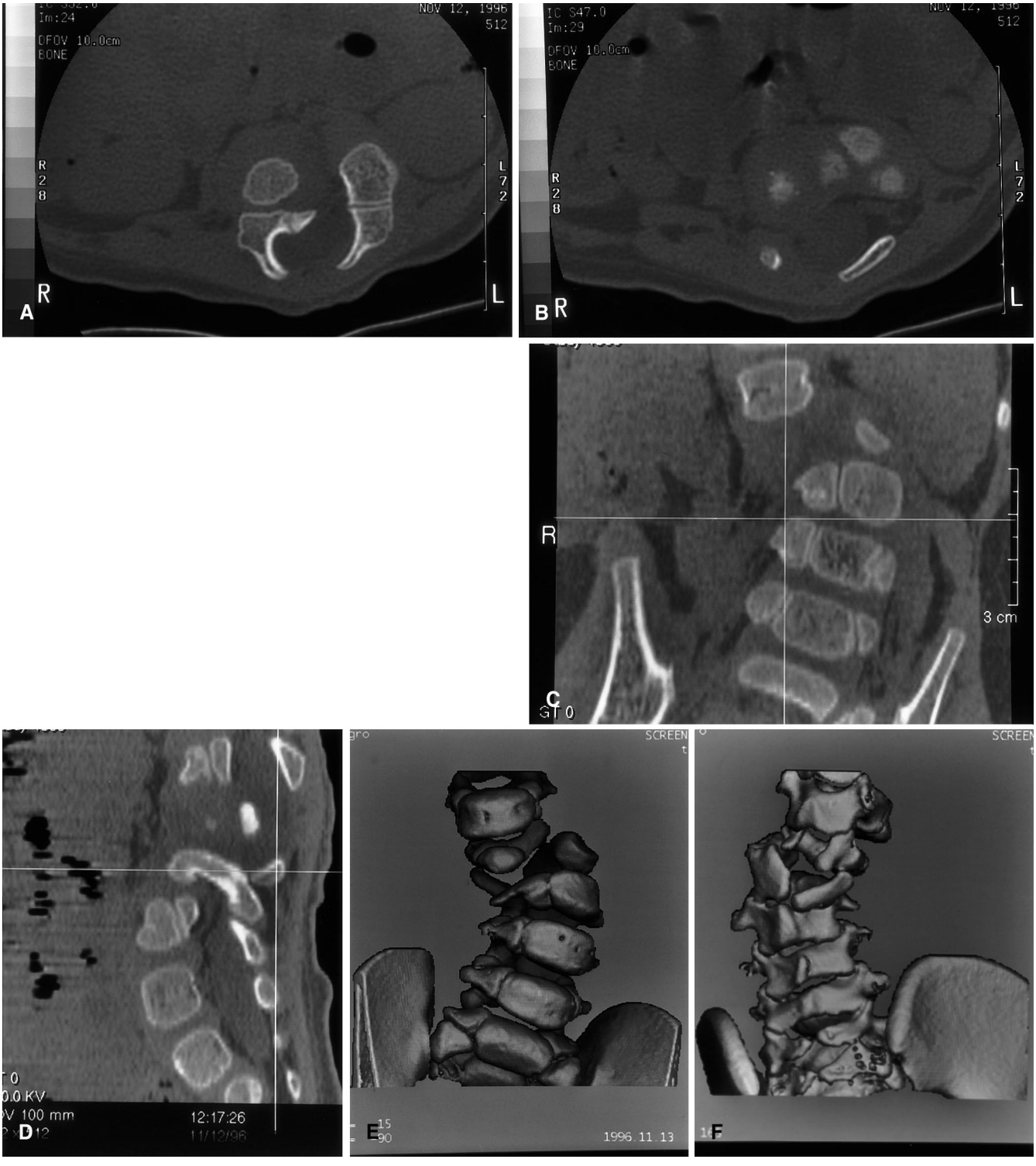

Abb. 5A–F A 15-month-old male infant with upper lumbar anomalies causing a sharp left scoliosis. Axial sections (**A, B**) and representative reformatted images (**C, D**) do not help in characterizing the anomalous segments. Only the 3D CT images (**E, F**) allow one to see the offset between the two bizarre unclassifiable anomalous segments and their potential for causing progression of the curve

with congenital scoliosis in which the potential for progression of deformity on the convex side of the scoliosis is arrested, while still leaving the patient with some capacity for growth on the concave side, which may lead to some correction of the deformity. Prophylactic convex

growth arrest is often employed in patients under 5 years of age in whom a documented progressive curve of less than 60° is present [9]. Patients with more severe deformity are often candidates for wedge osteotomy with correction and fusion, typified by the procedure of hemivertebra excision and fusion. This is a more extensive procedure than prophylactic convex growth arrest, carries a significant risk of spinal cord injury, and is usually reserved for deformities not satisfactorily managed by other methods, such as a lumbosacral junction hemivertebra causing a major structural imbalance.

Of the many different vertebral anomalies that can cause congenital scoliosis, unilateral unsegmented bars are the most common cause of progressive curvatures requiring surgical intervention. When associated with one or more segmented hemivertebrae on the contralateral side, the unilateral unsegmented bar is associated with severe, rapidly progressive curvatures [3]. Thus, the ability to assess the segmented or unsegmented nature of a hemivertebra can be crucial in clinical decision-making. However, the progressive distortion of vertebral morphology occurring in such children often obscures the presence of both the bar and the hemivertebrae on radiographs, especially in the older child. Conversely, the fact that unossified cartilage forms a significant component of the infant vertebra limits detection of unsegmented bars, which can be manifest only as intervertebral disc narrowing.

In the past, pluridirectional tomography was used in the detection of vertebral bars and other associated anomalies in patients with congenital scoliosis, but this imaging modality has largely been supplanted by CT. As the orientation of vertebral bars is often approximately perpendicular to the plane of section in conventional CT of the spine, such bars can prove difficult to detect on axial CT images. Further, visualization and classification of bars and hemivertebrae by CT is rendered problematic by the frequent severe distortion of vertebral morphology caused by spinal curvatures. Reformatted images produced from thin CT sections can detect unsegmented bars and detect and classify hemivertebrae in patients with congenital scoliosis, but these reformatted images, like the axial CT images, do not display the global morphology of the anomalous segments and their interrelationships in an easily perceived manner. Nevertheless, reformatted images were efficacious in demonstrating all but one of the bars in the patients in our series. MRI has been shown to be useful in the assessment of spinal dysraphism [10]. However, a comparison of MRI with the results of CT myelography and surgery in the investigation of various spinal disorders in children, in which five cases were of congenital scoliosis [11], concluded that MRI was of only limited usefulness in the characterization of vertebral anomalies, requiring lengthy examinations using multiple planes.

Diagnostic 3D CT of patients with congenital spinal curvatures requires meticulous attention to both CT technique and the 3D processing of the image data. Ease of density threshold seeding with CT images reconstructed with a low-frequency, soft tissue detail algorithm produces superior 3D images compared with images reconstructed with a bone detail algorithm. Improper thresholding can cause structures in close proximity to one another to appear fused, which can also occur with thicker CT sections. However, thinner sections contain more noise, which can also interfere with thresholding in older, larger patients.

Three-dimensional CT appears to be most useful in the minority of patients with congenital scoliosis in which the anomalies are complex, multiple, or obscured by deformity. Three-dimensional CT draws attention to morphologic features of complex vertebral anomalies which are inherently difficult to appreciate on planar images. It is hoped that this report will lead to a closer examination of the usefulness of 3D CT in the characterization of what are often exceedingly complex spinal malformations.

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