Evaluation of degenerative diseases of the lumbar spine with reformatted and 3-dimensional computed tomography images

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ABSTRACT

الأهداف: تقييم مدى التعرف على الآفات التنكسية للعمود القطني بواسطة الصور المُعاد بناؤها وذات المستويات المتعددة، بالإضافة إلى التصوير المقطعي الثلاثي الأبعاد.

الطريقة: أُجريت هذه الدراسة الاسترجاعية في قسم الأشعة، كلية الطب، جامعة سوتكو إمام، كاهرمان مارا، تركيا وذلك خلال الفترة من يناير 2006م إلى يناير 2009م. شملت الدراسة 53 مريضاً مصاباً بالآفات التنكسية للعمود القطني والتي ظهرت في صور الأشعة المقطعية. لقد قمنا بمراجعة الصور المُعاد بناؤها وذات المستويات المتعددة ثنائية الأبعاد، بالإضافة إلى الصور المقطعية الثلاثية الأبعاد. وبعد ذلك قمنا بتسجيل نتائج الصور المقطعية المُعاد بناؤها، ونتائج الصور المحورية. وأخيراً قمنا بتقييم الصور الثلاثية الأبعاد بواسطة نفس الفريق، وقمنا بتسجيل النتائج بنفس الطريقة.

النتائج: أشارت نتائج الدراسة إلى أن الصور المُعاد بناؤها وذات المستويات المتعددة ثنائية الأبعاد قد أعطت صوراً أوضح لتضيق الثقوب العصبية الأحادية الجانب لدى 62%، وانبعاج القرص لدى 32%، والانزلاق الغضروفي التنكسي لدى 15%، وداء الفقار لدى 15% وذلك عند مقارنة هذه الصور بالصور المحورية. كما أظهرت الصور المقطعية الثلاثية الأبعاد بوضوح كلاً من تضيق الثقوب العصبية الأحادية الجانب لدى 41%، والانزلاق الغضروفي التنكسي لدى 13%، وانزلاق الفقار للأمام الأحادي الجانب لدى 15% وذلك عند مقارنة هذه الصور بالصور المحورية والصور المُعاد بناؤها وذات المستويات المتعددة ثنائية الأبعاد.

خاتمة: أظهرت الدراسة بأن الصور المُعاد بناؤها وذات المستويات المتعددة ثنائية الأبعاد والصور المقطعية الثلاثية الأبعاد لها القدرة على إعطاء المعلومات التشريحية والتشخيصية التي لا يمكن الحصول عليها من خلال الصور المقطعية المحورية. كما أنها مفيدة في تقصي الآفات التنكسية للعمود الفقري والمضاعفات المترتبة من ذلك.

Objectives: To evaluate the identification of degenerative lesions of the lumbar spine with multiplanar reformatted images and 3-dimensional computed tomography (3DCT).

Methods: Fifty-three patients with degenerative spinal disease findings on lumbar CT scanning were reviewed in this retrospective study at the Department of Radiology, Medical Faculty, Sutcu Imam University, Kahramanmaras, Turkey between January 2006 to January 2009. Two-dimensional multiplanar reformatted and 3DCT images were obtained. First, the axial CT images, and then 2-dimensional multiplanar reformatted images (2DMPR) were evaluated. The findings seen on reformatted CT images that were not visualized, or visualized only in retrospect on axial images were recorded. Finally, the 3D images were evaluated by the same team. The results were again recorded in the same manner.

Results: When 53 patients were taken into account, the 2DMPR provided better visualization of lateral neural foraminal stenosis in 62%, bulging of the disc in 32%, degenerative retrolisthesis in 15%, and spondylolysis in 15% as compared to axial images. The 3DCT images clearly revealed the presence of lateral neural foraminal stenosis in 41%, degenerative retrolisthesis in 13%, lateral spondylolisthesis in 15% as compared to axial and 2DMPR.

Conclusion: The 2DMPR and 3DCT images provide significant anatomic and diagnostic information not readily derived from axial CT. It is useful in detecting degenerative conditions of the spine and associated complications.

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Degenerative lesions of the lumbar spine are related to various pathologies, which can affect the intervertebral disc, vertebrae, associated joints, intervening soft tissues, spinal longitudinal ligaments, and paraspinal muscles.[1] Many associated complications may occur including alignment abnormalities, intervertebral disc displacement, spinal stenosis, and calcification, or ossification. The CT images reliably demonstrate the bony details of vertebrae, as well as soft tissue pathologies.[1,2] With the advent of multislice helical CT systems, rapid data acquisition is possible with remarkably accurate results.[3,4] Rapid, thin-section multidetector volumetric acquisition allows a wide array of postprocessing capabilities, such as high-resolution 2-dimensional (2D) reformation, 3-dimensional (3D) volume-rendering, surface shading techniques.[5,6] The purpose of this study was to evaluate and compare the results of axial CT scans with 2D multiplanar reformatted (2DMPR) and 3DCT images from multidetector CT scans in symptomatic patients with degenerative disease of the spine.

Methods. The study was conducted between January 2006 to January 2009 at the Department of Radiology, Medical Faculty, Sutcu Imam University, Kahramanmaras, Turkey. Fifty-three patients (14 males, 39 females), with a mean age of 58 years (range: 43-85 years) who had CT findings of diffuse lumbar degenerative disease were included. The patients were referred from the neurosurgical or neurological department to the radiology department for CT examination of low back pain, lower extremity radiculopathy, motor, or sensory deficit of the lower extremities, or spinal claudication. Patients with intervertebral disc abnormalities, spinal stenosis (central canal, lateral neural foramina), spondylolisthesis (spondylolytic degenerative anterior, degenerative retrolisthesis), spondylolysis, lateral spondylolisthesis were included to our study group. Exclusion criteria included prior lumbar surgery, vertebral fractures, spinal infection or tumor, inflammatory spondyloarthropathy, and pregnancy. Due to the retrospective nature of this study the requirement for informed consent was waived. The CT examination of the spine was performed on a HiSpeed QX/I scanner (General Electric Medical Systems, Japan). Most of the scans were performed from the midportion of the first sacral vertebra to the midportion of L3. All examinations were carried out with a detector configuration of 4x1.25; beam collimation of 5.0 mm; pitch of 0.75:1; speed of 3.75 (mm/rot); slice thickness of 2.5 mm; 140kV 230 mAs; 16-cm field of view; and 0 degree gantry angulation.

Data sets were transferred to a workstation (Advantage Windows 4.0; General Electric Medical Systems, Tokyo, Japan). For MPRs, all scans were reformatted as contiguous one mm slice thickness using a bone and soft tissue window settings. Reformatted images were analyzed in multiple planes. For 3D reconstructions, images were created using the volume-rendered algorithm. The team evaluating the images from the selected patients consisted of 2 radiologists with more than 10 years of CT experience, and a neurosurgeon. The group reviewed each patient's images and together reached a consensus on the diagnosis. The image evaluation was carried out on digital workstation. Axial images were analyzed first, and radiological findings were noted. Then the patients' reformatted sagittal scans were evaluated in all cases. Reformatted coronal and oblique images were evaluated in selected cases. The findings seen on reformatted CT images that were not visualized, or visualized only in retrospect on axial images were recorded. Finally, the 3D images were evaluated by the same team. The results were again recorded in the same manner. Disc 'bulging' was diagnosed if there was concentric extension of the disc beyond the vertebral margin. Herniation was diagnosed when the disc extended beyond the bone in a focal and usually unilateral manner. Spinal stenosis was classified as central and lateral, including both foraminal and lateral recess stenosis. Central spinal stenosis was diagnosed when the anteroposterior canal diameter was <11.5 mm, or the interpedicular distance was <16 mm. Spondylolisthesis was graded as grade I (1-25%), grade II (26-50%), or grade III (51-75%). Lateral spondylolisthesis was present if the lateral edge of a vertebra compared with that of the vertebra below on the coronal reconstruction CT was higher than 3 mm.

Results. In cases in which more informative demonstration was afforded by 2DMPR over the axial images and the 3D over 2DMPR imaging were presented in **Table 1**. The 2DMPR images demonstrated better visualization in bulging of the disc, disc herniations (**Figures 1a & 1b**), central canal stenosis, degenerative anterior spondylolisthesis, isthmic spondylolisthesis (**Figures 2a & 2b**), degenerative retrolisthesis (**Figures 3a, 3b & 3c**), lateral neural foraminal stenosis, spondylolysis, and lateral spondylolisthesis over axial images. With a similar method of comparison, 3D images provided better demonstration in central canal stenosis, foraminal stenosis (**Figure 3c**), isthmic spondylolisthesis, degenerative anterior spondylolisthesis, degenerative retrolisthesis, spondylolysis, and lateral spondylolisthesis superior to the 2DMPR images.

Table 1 - Cases in which more informative demonstration was afforded by 2-dimensional multiplanar reformatted images (2DMPR) over the axial images, and the 3-dimensional over 2DMPR imaging.

Cases	n	(%)
2D MPR imaging are more informative over axial scans		
Intervertebral disc herniation		
Bulging of the disc	17	(32.0)
Disc herniations	6	(11.0)
Spinal stenosis		
Central canal	7	(13.0)
Lateral neural foramina	33	(62.0)
Spondylolisthesis		
Spondylolytic (isthmic) spondylolisthesis	3	(5.6)
Degenerative anterior spondylolisthesis	3	(5.6)
Degenerative retrolisthesis	8	(15.0)
Spondylolysis	8	(15.0)
Lateral spondylolisthesis	6	(11.0)
3D are more informative over 2D MPR images		
Spinal stenosis		
Central canal	4	(7.5)
Lateral neural foramina	22	(41.0)
Spondylolisthesis		
Spondylolytic (isthmic) spondylolisthesis	3	(5.6)
Degenerative anterior spondylolisthesis	2	(3.7)
Degenerative retrolisthesis	7	(13.0)
Spondylolysis	3	(5.6)
Lateral spondylolisthesis	8	(15.0)

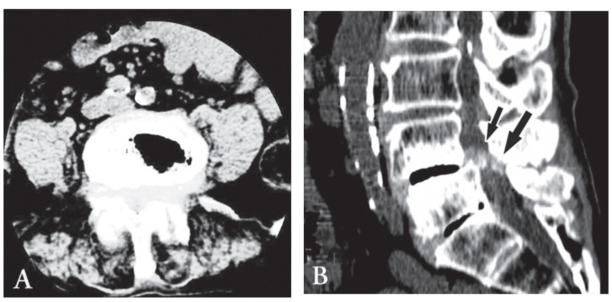

Figure 1 - Disc herniation of L4-L5 associated with degenerative spondylolisthesis and severe central stenosis in a 76 year-old man: **A**) axial computed tomography scan (soft window) of the most stenotic segment at L4-5, with a degenerative vacuum phenomenon shows diffuse protrusion of disc material at the same level as the spondylolisthesis; **B**) a 2-dimensional sagittal reformatted image clearly shows the extent and size of the disc herniation (short arrow) at the same level as the spondylolisthesis. The sagittal diameter of the spinal canal is seen to be severely compromised. Note hypertrophy of the ligamentum flavum (long arrow).

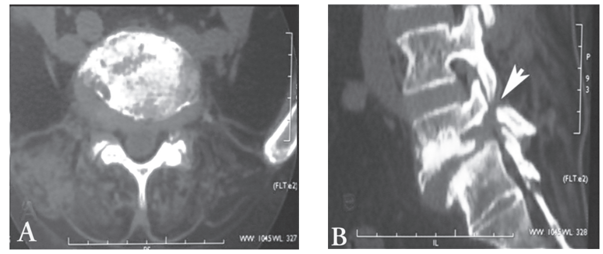

Figure 2 - Foraminal narrowing with isthmic spondylolisthesis in a 65-year old woman: **A**) axial computed tomography of L4-5 (bone window) demonstrates a pseudo-bulging disc and bilateral irregular pars interarticularis defects; **B**) 2-dimensional sagittal reformatted image (bone window) through the neural foramen confirms spondylolysis (arrow) and shows foraminal stenosis. The inferior part of the fractured pars is displaced downward. At the level of spondylolisthesis, the foramens are oriented horizontally rather than vertically. Note osteophytes from the narrowed disc space further compress the foramen.

Discussion.

Surgical treatment of low back pain varies according to the presence or absence of neurological compromise in light of degenerative conditions affecting the lumbar spine.[7] Before surgery is considered, precise information is needed, with regard to which lesion in the spine is responsible for the symptoms. Careful attention to patient selection and meticulous preoperative planning will allow an optimal surgical outcome.

In the literature, the major cause of failed back surgery syndrome was reported to be inappropriate decompression, or insufficient awareness of lateral stenosis of the lumbar spine.[8] This may still be true to a certain extent and improved visualization of foraminal stenosis in the lumbar spine is important. If osteophytes or foraminal bone lesions is overlooked and insufficient decompression is performed, symptoms will remain after treatment, and there is often a high risk that the patient will be regarded as a case of multiple operated back and left untreated.[8] Preoperative identification of such a condition would enable the incidence of failed back surgery to be reduced. Traditionally, conventional plain radiographs are the initial mode of investigation in many cases. A plain x-ray will show any osteophytes seen so commonly in spondylosis or degenerative disease,[9] however, these images can be difficult to interpret due to overlying structures obscuring the pathology and complexity of the disorder. The CT scans give more definition and delineation to the bony structures, and provide a 3D data set that can be manipulated by a computer to create cross-sectional images, and reconstructed views in various planes.[9] Different reformatted methods like MPR, volume rendering, and maximum intensity projection have the advantages and disadvantages in different diseases. Volume rendering

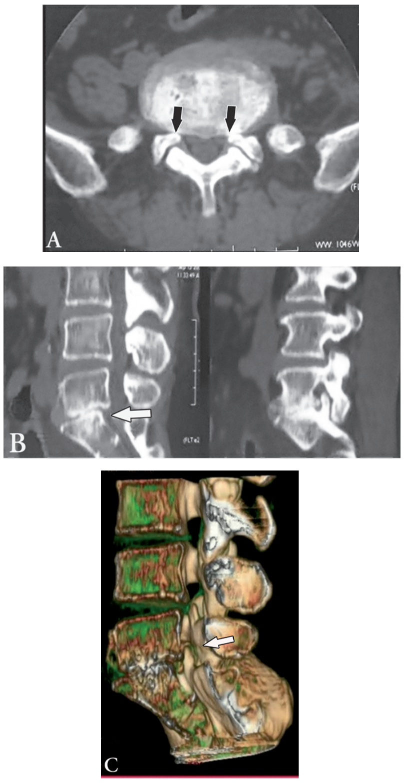

Figure 3 - Retrolisthesis of L5 on S1 in a 52 year-old woman; **A**) axial computed tomography scan at L5-S1 (bone windows) demonstrates characteristic forward displacement of superior facets (arrows) and widening of joint spaces. Degenerative changes in the apophyseal joints are minimal in contrast to joints in degenerative spondylolisthesis. **B**) 2-dimensional sagittal reformatted images (bone windows) demonstrate anterior displacement of S1 on L5 with progressive disc narrowing (arrow). Note the foraminal stenosis due to the upward displacement of the superior articular process. Osteophytes in the narrowed disc space further compress the foramen. Minimal retrolisthesis of L4 on L5 is also visible. **C**) this 3-dimensional sagittal image clearly shows severe foraminal stenosis (arrow) at the L5-S1 level.

is the preferred algorithm for all 3D musculoskeletal imaging applications, because it allows utilization of the entire CT data set in the creation of the 3D images, avoiding the extensive loss of information that is inherent in shaded surface rendering.[10] The VR images also maintain the original anatomic spatial relationships of the CT data set and have a 3D appearance, facilitating the display of complicated anatomic information to clinical colleagues.[10] The MR imaging is ideally suited in identifying pathology related to the soft tissues, including the disk, nerve roots, spinal cord, and ligaments, which are most often involved and causing symptoms in degenerative condition. Although no well-designed study has been performed, which conclusively proves the superiority of MR imaging over CT, most spinal radiologists consider this to be a fact, especially in more complex cases.[11] However, CT scans still have some advantages over MRI for the imaging of osseous lesions. The CT imaging with multiplanar reformation capability allows for bony detail, which is a limitation with MRI.[12]

The most common indication for lumbar CT examination is low back pain, with radicular pain to the lower extremity suggestive of disc pathology. Sagittal MPRs can be helpful to distinguish disc herniation from disc bulges and extruded disc fragments that may migrate caudad or cephalad in the epidural space.[2,13] We found sagittal CT reformatted images to be very useful in the diagnosis of annulus bulging, disc herniation (especially in spondylolisthesis patients), and migration of disc herniations. Degenerative spondylolisthesis with an intact neural arch is caused primarily by severe degeneration of facet joints and discs, and results from intervertebral joint instability in combination with progressive disc narrowing. Focal stenosis of the canal below the pseudo-bulging disc may be present, along with a decrease in cross-sectional diameter of the neural foramina.[2,14-16] The pseudo-bulging disc is a major CT finding in spondylolisthesis.[16] When there is minimal slippage, a pseudo-bulging disc can be misinterpreted as a herniated disc if one evaluates axial CT images alone. We avoided misdiagnosing herniated discs by closely analyzing our sagittal reformatted images.

The use of reformatted sagittal scans can help evaluate the degree of foraminal and spinal stenosis caused by spondylolisthesis.[2,14,15,17] On axial CT scans, pars defects often simulate the adjacent facet joints because both the joints and defects are oriented in similar planes and separated by only a small distance.[6] The sagittal plane is the optimal plane for evaluating the entire pars inter-articularis, because the obliquity in this plane is minimal.[18] Our results showed that sagittal MPRs can clearly demonstrate very small degrees of slippage of a vertebral body that are not clearly recognized on axial CT. The type and severity of spondylolisthesis can also be classified more accurately, and the entire pars interarticularis visualized more completely with sagittal reconstructions.

Degenerative spinal stenosis of the lumbar spine is caused by many factors, some of which include disc bulging and herniation, ligamentum flavum hypertrophy, facet joint hypertrophy, and spondylolisthesis.[2,19] In this study, the outline of the spinal canal was demonstrated very adequately on axial and sagittal MPRs. The lateral recess usually contains the descending nerve that has just exited the dural sac. Stenosis mainly results from hypertrophy of the superior facets.[19] The most common cause of surgical failure is inadequate decompression of the nerve in the lateral foramen.[8] For many years, the intervertebral foramen was known as a 'hidden zone', as diagnostic imaging of this area was particularly difficult.[8] While CT images in the axial plane permit AP and transverse measurements only in the sagittal plane, the entire bony margin of the neuroforamina can be visualized.[19] The size and configuration of the neuroforamina are more easily determined on reconstructed images. Encroachment of the superior recess of the neural foramina is detected in many patients who have spondylolysis at L5-S1, but may not be obvious on axial images. This encroachment may be significant because of the usual anatomic location of the exiting spinal nerve root.[18] Reformatted oblique sagittal scans are advantageous when bony stenosis occurs principally in the vertical dimension.[17] Our sagittal images demonstrated lateral neural foraminal compromise better than the axial images. The CT can show narrowing of the lateral recess and neural foramina, especially on sagittal reconstructions. These images are especially valuable for the preoperative evaluation of affected neural foramens in patients with lateral stenosis.

Scoliosis with progressive deformity can develop later in life. Scoliosis may cause suprajacent vertebrae to slip laterally on a subjacent one, resulting in laterolisthesis, which may have a rotational component. These changes together may cause ipsilateral stenosis of the lateral recess of the spinal canal and ipsilateral spinal neural foramen.[20,21] Multiplanar reformatting allows imaging parallel to the discs in patients with scoliosis, which optimizes the evaluation of the disc, facet joints, and neural foramina. The 3DCT imaging provides more information than direct axial and 2DMPR images.[22] Obtaining 3D images in scoliosis patients, enables one to evaluate lateral neural foraminal narrowing, and to identify more clearly any degree of slipping of a vertebral body. An additional benefit associated with 3DCT imaging is improved correlation of the images with intraoperative anatomy. Although we did not study this specifically, we believe it allows more accurate confirmation of the surgical level when the intraoperative view can be compared with the 3D CT images.

There are several limitations to our study. The limits of CT resolution of soft tissues could make it difficult to depict the imaging findings especially at the vertebral pedicles and lamina, where the dural sac is entirely surrounded by a ring of bony structures. As this is a retrospective radiological study clinical data were flatly-described, and this may be the weakness of this study, but our aim was to investigate and emphasize the usefulness of multiplanar 2D and 3D images on degenerative spinal lesions as compared to axial CT scans, and not to correlate our results with the surgical findings and treatment results, which may be the aim of future studies.

In conclusion, the CT with multiplanar reconstruction provides additional anatomic and diagnostic information not readily derived from axial CT scans, especially complex degenerative conditions of the spine and their complications, such as spondylolisthesis, spinal stenosis, disc herniation, and foraminal narrowing. In our study, 2D sagittal reformatted images and 3D CT appear particularly useful in the identification of foraminal lesions. Despite the additional cost of this advanced imaging, the visualization and understanding subtle degenerative lesions causing neural compromise is beneficial especially to the spine surgeon. In our opinion, MPR imaging or 3DCT of the lumbar spine can be added in patients who have degenerative lesions on their plain films, or MRI examinations in order to improve the results of the treatment.

Future studies should compare 2D images with MRI images in order to identify the sensitivity and specificity of reformatted CT images more clearly, and to evaluate the insensitive areas of MRI scans in spinal pathology cases. Fusion imaging of the lumbar spine with 3-D MRI/CT techniques can also be the aim of the future research.

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