Three Dimensional Spiral CT Imaging of the Musculoskeletal System: Application and Advantages

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Abstract

Background: Clinical applications of spiral computed tomography (CT) have increased extensively over the past decade and continue to widen rapidly. The introduction of three-dimensional(3-D) reconstruction in CT technology has revolutionized medical imaging. This advancement has been possible due to the combination of spiral computed tomography and various 3-D reconstruction protocols which have permitted rapid and comprehensive examination of all regions of the body. It has unequivocal advantages in the preoperative planning of craniofacial surgery, assessment of complex fractures of the skeletal system especially pelvis and in the surgical treatment of dysplastic hips in children.

Methods: 3-D spiral CT imaging of various parts of the musculoskeletal system was carried out in 60 cases using available protocols, at the CT scan center of a large tertiary care service hospital .

Results: The study provided a new approach in the analysis of complex anatomic relationships of the musculoskeletal system. Therapeutic planning whether surgical or medical was to a great extent aided by the anatomic information available from these images.

Conclusion: 3-D CT imaging is a rapid, non-invasive and accurate technique for diagnosis, pre-operative evaluation as well as post-operative assessment of a large number of musculoskeletal diseases. 3-D CT studies have come to stay and with continued improvement in CT technology it has now become an integral part of imaging studies of the musculoskeletal system.

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Key Words: Spiral CT; 3-dimensional imaging; Musculoskeletal system

Introduction

Although Magnetic Resonance Imaging (MRI) is the modality of choice for imaging the musculoskeletal system; Spiral CT remains a viable alternative. Spiral CT is faster, less expensive, easily available and has the potential to evaluate a wide range of musculoskeletal diseases, thus making it an important diagnostic tool [1]. The availability of new algorithms and better computer generated software for multiplanar and 3-D image reconstruction has further enhanced the importance of Spiral CT in musculoskeletal imaging.

The use of 3-D reconstructions of spiral CT in the musculoskeletal system is of tremendous advantage to patients in whom CT is desired to delineate the presence and extent of congenital anomalies, traumatic injury, tumour, infection and inflammation [2]. It also has specific role in postoperative evaluation, especially when the results of plain radiography fail to answer the doubts of the orthopaedic surgeon regarding satisfactory alignment of complex fractures [3]. 3-D CT imaging is able to compensate for streak artifacts due to the presence of metallic implants such as plates, pins and prostheses and because of this it is an established

modality for postoperative cross-sectional imaging in orthopaedic patients also.

Material and Methods

A total of 60 3-D spiral CT imaging studies of the musculoskeletal system were carried out at the CT scan center of a large service hospital, during a six month period from June 2002 to November 2002 on patients ranging from a few months to 68 years of age. The investigations were carried out on a Philips Tomoscan AV spiral CT scanner with a gantry rotation period of one second.

The various anatomic regions studied using 3-D spiral CT are depicted in Table 1. To achieve best results with accurate illustration of the musculoskeletal anatomy and pathology, examination techniques need to be optimized, and to achieve this, imaging protocols that were followed are given in Table 2.

Using the protocols described above axial CT data obtained was reconstructed at 0.5 to 1 mm intervals with segmented interpolation and a restricted field of view of 16 to 18 cm. This yielded 180 to 320 images which were then sent to a work station for 3-D reconstruction which was done using shaded surface display (SSD) and volume rendering (VR) algorithms.

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Table 1

Distribution and clinical indications of 3-D CT imaging.
N=60

Region	Indication	Number of patients
Congenital and development anomalies of skull		
	• Craniostenosis	3
	• Apert's syndrome	1
	• Craniofacial fibrous dysplasia	2
Craniofacial trauma		
	• Fracture Maxilla	3
	• Fracture Mandible	8
	• Fracture Orbital walls	4
Tumours		
	• Osteosarcoma of Femur	3
	• Osteochondroma of Femur	2
	• Ameloblastoma of Mandible	3
	• Meningioma	2
Pelvic Trauma		
	• Comminuted fractures of Pelvis	5
	• Fracture head of Femur	2
	• Fracture Acetabulum	5
Avascular necrosis of head of Femur		
	• Following trauma	3
	• Following posterior dislocation of hip	2
Post operative evaluation		
	• Craniofacial surgery	7
	• Pelvic surgery	5

Results

The axial and 3-D SSD images of the patients under study were analysed. A total of 6 patients with developmental anomalies of the skull underwent 3-D CT scanning; of these 3 patients had primary craniostenosis, two had craniofacial fibrous dysplasia and one had Apert's syndrome.

Craniofacial trauma formed the largest group on whom 3-D CT studies undertaken, a total of 15 patients were evaluated using this imaging modality. Various fractures of the mandible, maxilla and orbit could be accurately delineated. 3-D CT imaging was performed in 10 patients with bone tumours; of these 3 patients had osteosarcoma of the femur, 2 had osteochondroma of the femur and tibia, 2 patients had calcified meningiomas and 3 had ameloblastoma of the mandible.

A total of 12 patients with complicated fractures of the pelvis were evaluated with 3-D CT.

Five patients with avascular necrosis of the head of femur underwent 3-D CT to assess and grade the severity of necrosis.

Post operative evaluation of the musculoskeletal system is an important indication of 3-D CT imaging and in the present study 12 patients underwent CT scanning with 3-D reconstructions for evaluation of their post operative status.

Discussion

Creation of a 3-D CT image begins with the acquisition and then reconstruction of these axial image data subsets into either SSD or volume rendered reconstructed image. Both these algorithms have been extensively applied to CT data for 3-D visualization of skeletal pathology however each has its potential limitations. Certain

Table 2

Protocols used for data acquisition for 3-D CT imaging

Region	Slice thickness (mm)	Table speed (mm/s)	Field of view (FOV) (mm)
Skull	1	2-3	160-180
Craniofacial	1	3	180-200
Tumours	2	4	120-180
Pelvic trauma	2	3	120-150
Avascular necrosis of femoral head	2	4-5	120-150
Post Op evaluation	3	5-6	120-150

disadvantages of SSD makes volume rendering a preferred algorithm for 3-D musculoskeletal imaging applications.

Surface rendering shows gross 3-D relationships most effectively, but suffers from additional stair-step artifacts and fails to efficiently display lesions hidden behind overlying bone or located beneath the cortex. Volume-rendering algorithms show subcortical lesions and minimally displaced fractures better and with fewer artifacts. In the present study both the 3-D rendering algorithms for musculoskeletal imaging have been used.

Comprehensive understanding of sutural anatomy and skull deformity is important for the diagnosis and surgical correction of craniostenosis. To achieve this 3-D imaging is most often resorted to as 2-D CT studies alone fail to detail the relationships of the axially oriented structures. Studies have suggested that 3-D reconstruction is a more accurate method in diagnosing craniostenosis than thin section axial CT images alone [4], because 3-D CT can depict suture patency, extent of synostosis (i.e., complete versus incomplete bone bridging) and associated calvarial deformities. In the present study three patients with suspected craniostenosis underwent 3-D CT studies and in all of them craniostenosis was confirmed, two patients had stenosis of the sagittal suture with dolichocephalic skull and one had stenosis of the coronal suture with brachycephalic skull. One child with Apert's syndrome underwent 3-D CT studies to delineate the extent of stenosis of the sutures and associated craniofacial anomalies. The study revealed craniostenosis involving the coronal sutures with resultant turri-brachycephalic skull; the midline of the calvaria had a gaping defect, extending from the glabella to the posterior fontanelle via the metopic suture, anterior fontanelle and sagittal suture (Figs 1 & 2). The child also had associated bilateral choanal atresia. 3-D CT imaging provided precise delineation of the various craniofacial defects which led to an effective pre-operative planning and the child was taken up for successful surgery. Two patients with polyostotic craniofacial fibrous dysplasia underwent 3-D CT studies which demonstrated thickening and enlargement of the

Fig. 1 : Lateral CT Topogram of skull of a 3 month infant with Apert's syndrome showing fused coronal suture

Fig. 2 : 3D CT of child with Apert's syndrome showing fused coronal suture with gaping metopic and sagittal sutures

base of anterior cranial fossa along with narrowing of the superior orbital fissures and the optic canals. These patients also underwent surgery to relieve the narrowing of the superior orbital fissures and optic foramina. 3-D CT imaging in congenital and developmental craniofacial anomalies is important in the pre-operative evaluation and therapy planning than in diagnosis and the results are much better than plain radiographs and 2-D CT scans [5].

The major utilization of 3-D CT imaging in this study was in the evaluation of craniofacial trauma. A linear

Fig. 3 : 3D CT showing multiple fractures of the mandible

fracture if oriented in the plane of the CT section may be missed on routine axial 2-D CT and it is here that the role of 3-D CT imaging is invaluable. This modality of imaging is of great help in evaluating complex maxillary, mandibular and orbital fractures as it accurately depicts comminuted fractures, describes in detail the relationship of the bone fragments to each other, to the bone of origin and adjacent structures [6]. Rotated fractured bone fragments are better evaluated using 3-D CT imaging as they can be viewed from innumerable angles and be compared to the normal contralateral side. Sometimes subtle rotational abnormalities can only be appreciated on 3-D images. In the present study 15 patients underwent 3-D CT imaging for craniofacial injuries out of which 9 had complicated comminuted fractures involving the mandible and maxilla (Fig 3). The exact amount of gap between the fractured ends of the bone, precise localization of the bone segments and the relationship of these fragments to the bone of origin and to each other was accurately assessed. Another patient who developed a palatal fistula as a result of gun shot wound in the maxilla was evaluated using 3-D CT imaging. The precise anatomy of the bony defect in the maxilla and the hard palate was delineated and the patient was successfully operated (Fig 4). Thus 3-D CT imaging is an important means to diagnose and exemplify complicated craniofacial fractures and provide a foundation for effective pre surgical management in these patients.

Although plain radiography and MRI remain the mainstay in evaluation of tumours of the bone, studies conducted by the Radiology Diagnostic Oncology

Fig. 4 : 3D CT image showing large defect in the maxilla and palate due to gun shot wound

Group [7] have shown that CT is not only as efficacious but is superior to MRI in the detection of cortical destruction and calcification. In the present study 3-D CT imaging was performed in a total of 10 patients with tumours in various regions of the body. Five patients had primary bone tumours which included osteosarcoma of the lower end of femur in three and osteochondroma of the femur and tibia in two. Two patients had large calcified meningiomas; one arising from the sphenoid ridge on the left side and the other was a large right sided parasagittal meningioma. The aim of performing 3-D CT in patient with meningiomas was to get a true assessment of the extent of the lesion, acquire a global view of the tumour and to evaluate the bone of origin. Three patients who had ameloblastoma of the mandible also underwent 3-D CT imaging which provided a precise anatomic representation of the mass lesion with accurate depiction of the extent of spread (Fig 5). This allowed accurate pre-operative diagnosis and provided the surgeons with good pre and intraoperative conceptualization of the lesion which improved respectability and reduced the duration of surgery thereby providing better surgical outcome.

3-D CT has a specific role in radiation therapy planning; it reassembles the 2-D CT images into a more intuitively obvious shape which simulates the anatomic form thereby helping the radiotherapist to visualize the relationships between tumour target, normal tissue and delivered dose. Another advantage of 3-D imaging is that it can calculate tumour volume pre-operatively which can be compared with the volume of tumour resected on surgery, this will establish whether the tumour has been removed completely or not.

Fig. 5 : 3D CT showing Ameloblastoma of the Right Mandible

Fig. 6 : 3D CT of pelvis showing comminuted fractures of the Acetabulum on the Right side

Pelvic injury is a major cause of morbidity and mortality following trauma, the average mortality associated with it being 18-24% [9]. Radiological evaluation of the injured pelvis has been simplified with the advent of CT which apart from providing cross-sectional display of structures; has the ability to distinguish bone, soft tissue, muscle, pelvic organs and fat with great accuracy. However planar axial CT too has limitations, it may underestimate or even overlook the presence of fractured fragments lying entirely in the transaxial plane. These potential limitations can be overcome by the use of 3-D imaging; it is now possible to reformat the transaxial CT data into 3-D images which allow an integrated CT imaging approach in which conventional CT images are first evaluated followed by 3-D reconstruction. The anatomy of interest can be rotated through innumerable positions in any 360° sequence until the best view is obtained so that the viewer

Fig. 7 : Grade II avascular necrosis of the head of Right Femur as seen on 3D CT

can study the various surfaces of the pelvis. In the present study 12 patients with complicated fractures of the pelvis underwent 3-D CT imaging to assess the nature and degree of fractures. In all the patients the fractures were comminuted with multiple bone fragments lying separately from the bone of origin (Fig 6). On axial planar CT all the fractures could not be identified and the bone of origin of the separated fragments could not be ascertained, thus making 3-D imaging mandatory. Intra-articular bone fragments causing subluxation of the hip joint could be easily identified. Moreover it provided the surgeon with an overview of the entire pelvis as it would appear on surgery thereby helping him in planning accurate management. Thus 3-D CT imaging is valuable in defining the full extent of pelvic trauma and is particularly useful in showing the spatial relationship of fragments before surgical management.

Although MRI is considered to be the gold standard in the evaluation of avascular necrosis of the femoral head, with a sensitivity of 97% and specificity of 85% [10], spiral CT too has a specific role in its diagnosis and staging. With the introduction of 3-D imaging it is possible not only to accurately diagnose the lesion but also stage it, which has a direct bearing on the surgical procedure to be employed. Early detection of avascular rotational osteotomy or core decompression with or without vascularized grafting initiated in the initial period lead to preservation of joint function [11]. In the present study 5 cases of avascular necrosis of the femoral head underwent 3-D CT imaging which clearly delineated areas of sclerosis, compression and contour alteration of head of femur along with acetabular involvement (Fig 7). It has been confirmed by various studies that CT examination upgraded staging in 30% of the hips studied [12] moreover asymptomatic and radiographically normal contralateral hips were found at CT to have stage II or

Fig. 8 : Post hemimandibulectomy (Right) with fibular graft as seen on 3D CT

even stage III avascular necrosis. Subtle alterations in femoral-head and acetabular contours joint spaces are very well defined on CT which are not seen on plain radiographs. CT studies with 3-D imaging has made significant contributions to the diagnosis and staging of avascular necrosis of femoral head and has consequently altered the choice of surgical management to the benefit of the patient.

The role of 3-D imaging in post operative status evaluation is unsurpassed as compared with other imaging modalities. Plain radiographs do not provide the required information, moreover there is so much of overlap of adjacent structures that correct interpretation is not always possible. MRI may be contraindicated due to the presence of metallic implants or may produce artifacts which interfere with accurate interpretation of images. 3-D CT imaging not only provides accurate delineation of the bony contours and relationship of the bones forming the joints, it also assesses the spatial relationship of the orthopaedic hardware to the parent bone. In the present study 12 patients underwent 3-D CT imaging for evaluation of their post operative status; out of these 5 patients had undergone craniofacial surgery with metallic implants, 3 had undergone hemimandibulectomy with fibular grafts (Fig 8) and 4 patients had internal fixation implants in the pelvis. Cross-sectional imaging in post operative patients has traditionally been a source of frustration for both the radiologist and the orthopaedic surgeon because CT images are limited by streak and MR images by susceptibility artifacts. Spiral CT with advanced 3-D imaging eliminates most streak artifact and produces high-quality images depicting perfectly the relationships between hardware, bones and joints.

Thus spiral CT is a powerful modality for evaluation of the musculoskeletal system, particularly when coupled with advanced 3-D imaging features. This modality of imaging has become an important part in the evaluation of musculoskeletal disease and its inclusion in routine musculoskeletal imaging protocols has changed the diagnosis and management in a significant number of cases.

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Second Best Article Award

Maj SK Roy Chowdhury, Brig S Murali Mohan "*Maxillofacial Injuries in Counter Proxy War Posture of the Armed Forces*". MJAFI;2004; 60(4): 357-362.