ORIGINAL RESEARCH

Experimental comparative study of Two-dimensional and Three-dimensional CT reconstruction in detecting maxillofacial fractures at Mzuzu Central Hospital, Malawi

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Abstract

Objective:

The aim of this study is to compare the diagnostic value of two-dimensional (2D) CT and three-dimensional (3D) CT reconstruction techniques in detecting maxillofacial fractures in patients at Mzuzu Central Hospital (MCH).

Methods

67 maxillofacial trauma patients admitted to Mzuzu Central Hospital from Jan to Sep 2024 underwent multi-slice spiral CT (MSCT) scanning. Images were post-processed using 2D and 3D reconstruction techniques. Clinical and radiological data were collected from the patients, and a comparative analysis of the results from the two reconstruction techniques was performed.

Results

In this study, 52 cases of maxillofacial fractures with a total of 83 fractures were diagnosed by 2D CT reconstruction technology, with a fracture detection rate of 77.61% (52/67). Using 3D CT reconstruction technology, 54 cases of maxillofacial fractures with a total of 91 fractures were diagnosed, and the fracture detection rate was 80.60% (54/67). Statistical analysis showed no significant difference in the detection rate of maxillofacial fractures between 2D CT and 3D CT reconstruction ($\chi^2 = 35.945$, $P = 0.687$). In the diagnosis of zygomatic fractures, nasal fractures, and upper and lower jaw fractures, 3D CT reconstruction images have obvious advantages over 2D CT in displaying fracture displacement and fracture line course. However, for the display of comminuted fractures combined with sphenoid and ethmoid fractures, the cross-sectional images of 2D CT show higher superiority.

Conclusion

2D CT reconstruction is a basic diagnostic tool for maxillofacial fractures. 3D reconstruction, with high detection and multi-angle visualization, offers valuable imaging for clinical decision-making, aiding in surgery planning. A combined approach, leveraging the strengths of both modalities, is pivotal for comprehensive assessment and management of maxillofacial trauma.

Key words: Multi-slice spiral CT; Three-dimensional reconstruction; Maxillofacial fractures; Maxillofacial trauma

Introduction

The facial bones, along with their bony connections, form the lower portion of the skull, shaping the basic contour of the face[1-3]. Together with the neurocranium, they protect the brain tissue, and maintain facial symmetry and proper positioning of the sense organs[4]. The facial bones include the zygomatic bone, nasal bone, maxilla, lacrimal bone, vomer (forming the bony nasal septum with the perpendicular plate of the ethmoid bone), palate, inferior nasal concha, mandible, and hyoid bone. Fractures of facial bones are often caused by sudden accidents such as traffic accidents, falls from heights, and assault injuries. Jaw and facial trauma is often accompanied by soft tissue and craniocerebral injuries, especially in the base of cranium and mandible[5,6]. Due to the vascularization in this area, profuse bleeding after injury, and soft tissue edema can compress the respiratory tract, leading to life-threatening suffocation. Clinical diagnosis of fractures primarily relies on medical imaging techniques. However, the complex anatomical structure of the jaw and face makes diagnosis challenging, as fractures can easily involve adjacent tissues, and different fracture patterns overlap, increasing the complexity and diversity of jaw and facial fractures[7,8].

Patients with fractures are typically examined using X-ray, but these are 2D images that cannot clearly show the location and displacement of complex fractures[9-11]. Furthermore, accurate positioning is crucial for X-ray radiography, which is often difficult to achieve due to compliance, leading to suboptimal image quality[12]. Axial CT scans display 2D images that avoid image overlapping compared to previous X-ray plain films, significantly improving detection rates[13,14]. However, they lack 3D information, making it difficult to accurately, comprehensively, and clearly assess the extent and severity of jaw and facial fractures, limiting their clinical utility for fracture diagnosis and treatment. MSCT volumetric scanning not only offers fast imaging but also reveals fracture lines and spatial relationships in complex fractures across different planes of the jaw and face. Additionally, 2D

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and 3D reconstructions offer a more comprehensive and spatially accurate representation of the images. Relevant studies have shown that 3D reconstruction technology has significant advantages over 2D reconstruction in diagnosing maxillofacial fractures, particularly in assessing the extent of bone damage and fracture displacement. It can serve as the gold standard investigation in case of different maxillofacial fractures[15]. However, 3D CT reconstruction requires advanced post-processing workstations and skilled technical operation and image interpretation capabilities, which may be challenging for general clinicians to analyze in detail, necessitating reliance on specialized radiologists. As the most important tertiary referral hospital in the northern region of Malawi, Mzuzu Central Hospital (MCH) has only one senior radiologist in its radiology department, which presents a substantial challenge for the imaging evaluation of maxillofacial fractures. This study aims to explore and compare the diagnostic value of 2D CT and 3D CT reconstruction techniques in detecting maxillofacial fractures in patients at MCH, and to evaluate whether the more user-friendly 2D reconstruction technique can be routinely used for diagnosing such fractures.

Methods

General Information

A retrospective analysis was conducted on the clinical data of 67 patients with maxillofacial trauma admitted to MCH from January 2024 to September 2024. Inclusion criteria was as follows: patients aged 18 years or older, diagnosed with maxillofacial trauma upon admission, exhibiting clinical manifestations such as pain, limited mouth opening, disturbed occlusion, facial swelling, and deformities, and underwent 16-slice spiral CT examination prior to treatment. Exclusion criteria encompassed patients under 18 years old, those with incomplete imaging data, poor treatment compliance, mental illnesses, or inability to complete the examination. Among the 67 patients, 35 were male, and 32 were female, with ages ranging from 18 to 61 years old, averaging at (35.97 ± 6.71) years. Causes of injury included 34 cases of traffic accidents, 17 cases of assault, 14 cases of falls, and 2 cases of other causes. This study was approved by Mzuzu University Research Ethics Committee (MZUNIREC) (Approval Number: MZUNIREC/DOR/24/153), and consent in written form was waived.

CT Examination

A NeuViz 16 Essence CT scanner, independently developed and produced by Neusoft Medical, was utilized for volumetric scanning. Patients were positioned in the supine position, and a lateral skull localization image was acquired. The scan baseline was set at the mandibular angle, with a scanning range extending from 4 cm above the superior orbital margin to 4 cm below the inferior mandibular margin. For CT volumetric scanning, an appropriate scan field of view (FOV) was selected, with a tube voltage of 120 kV, tube current of 280 mA, rotation time of 1s per revolution, and a scan duration of 3-4 seconds. The raw data acquisition utilized a scan layer thickness of 16 mm × 0.625 mm, a collimation of 40 mm, a continuous scan layer thickness of 5 mm without intervals, and a pitch of 1.00.

Image Processing and Analysis

All data were transferred to a delicate workstation for post-processing, involving a bone algorithm and a moderately smoothed soft tissue algorithm reconstruction. Bone window settings were 300-700 HU with a window width of 1500-3000 HU, while soft tissue window settings were 35-45 HU with a window width of 300-400 HU. Images were rotated at any angle as needed. The software's cutting function was employed to remove cervical vertebrae and part of the skull base, and the optimal image for lesion display was selected for storage. 3D reconstruction methods included multiplanar reconstruction (MPR), shaded surface display (SSD), maximum intensity projection (MIP), and volume rendering (VR). Two experienced radiologists independently evaluated the maxillofacial CT plain scan images and CT 3D reconstruction images using a double-blind method, consulting until a consensus was reached in cases of disagreement.

Statistical Analysis

Data were analyzed using SPSS 22.0 (IBM, Chicago, USA). Count data were presented as percentages (%), and intergroup comparisons were performed using the χ^2 test. Kappa testing was applied to assess the consistency of the subjective evaluations by the two radiologists: a Kappa value of 0-0.4 indicated poor agreement, 0.4-0.6 moderate agreement, and 0.6-1.0 good agreement. A P-value <0.05 was considered statistically significant.

Results

The two radiologists demonstrated good agreement in image assessment, with Kappa values of 0.832 and 0.856 for maxillofacial 2D and 3D CT reconstruction images, respectively.

Through 2D CT reconstruction images, 52 cases of maxillofacial fractures were diagnosed, involving a total of 83 fracture sites, with a detection rate of 77.61% (52/67). Among these, 25 cases were diagnosed with multiple maxillofacial fractures. 3D CT reconstruction identified 54 cases of maxillofacial fractures, encompassing 91 fracture sites, with a detection rate of 80.60% (54/67), including 25 cases of multiple maxillofacial fractures. There was no statistically significant difference in the detection rates of maxillofacial fractures between 2D CT and 3D CT reconstruction (χ^2 = 35.945, P = 0.687).

The specific fracture locations are detailed in Table 1, with maxillary and mandibular fractures being the most common. 2 (2/54) cases were missed by 2D CT compared with 3D CT, one involving a nasal bone fracture and the other a mandibular condyle fracture. A total of 8 (8/91) fractures were not found on 2D CT reconstruction images (2 zygomatic fractures, 2 nasal bone fractures, 2 maxillary fractures, 1 mandibular fracture, and 1 inferior turbinate fracture). Among the 54 patients with maxillofacial fractures, 7 (12.96%) had mandibular condyle fractures, with 3 cases accompanied by temporomandibular joint dislocation. Among them, 7 patients with mandibular condylar fractures were fully visible on 3D CT reconstruction images, and 6 patients were shown on 2D CT reconstruction images. 5 cases (9.26%) involved mandibular body fractures, which were discernible on both 2D and 3D CT reconstruction images. Six cases (11.11%) presented with multiple fractures in the mandibular body and ramus, with 3D CT reconstruction providing superior visualization of fracture lines and fragment displacement compared to 2D CT reconstruction.

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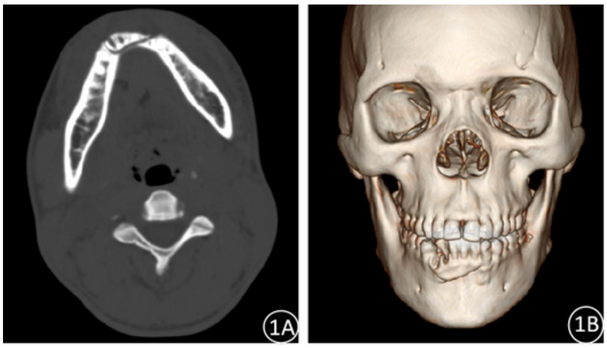

Figure 1 Two-dimensional reconstruction bone window shows median mandibular fracture involving alveolar bone (A); three-dimensional reconstruction imaging of median mandibular and alveolar bone fracture (B)

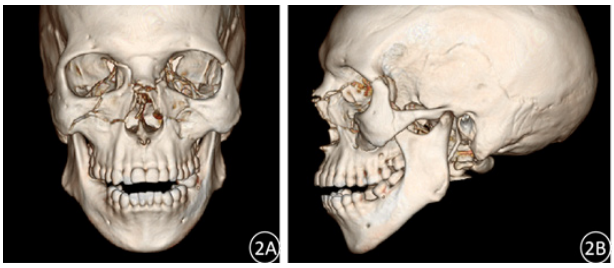

Figure 2 Three-dimensional reconstruction VR images of a patient with multiple complex maxillofacial fractures. Comminuted fractures of the maxilla and nasal bones on both sides (A); left zygomatic arch fracture (B)

Table 1 Comparison of Scan Results for maxillofacial fractures between 2D and 3D CT Reconstruction [n (%)]

Fracture Location	2D CT Reconstruction	CT 3D Reconstruction
Maxillary Fracture	23 (27.71%)	25 (27.47%)
Mandibular Fracture	28 (33.73%)	29 (31.87%)
Zygomatic Fracture	11 (13.25%)	13 (14.29%)
Nasal Bone Fracture	15 (18.07%)	17 (18.68%)
Inferior Turbinate Fracture	3 (3.61%)	4 (4.40%)
Lacrimal Bone Fracture	3 (3.61%)	3 (3.30%)
Total	83	91

Sixteen patients (29.63%) had comminuted fractures of the maxilla and mandible, with 11 cases accompanied by zygomatic fractures, 7 with ethmoid fractures, 8 with nasal bone fractures, and 5 with sphenoid fractures. Both 2D and 3D CT reconstruction images provided good visualization of maxillary and mandibular fractures (Figures 1 and 2), zygomatic fractures, nasal bone fractures, and comminuted zygomatic arch fractures. However, only 9 (9/12) cases with concomitant ethmoid and sphenoid fractures were well-displayed on 3D CT reconstruction images, while all were visible on axial 2D CT reconstruction images.

Discussion

In Malawi, a country located in the southeastern region of Africa, rapid economic growth coupled with the widespread adoption of motor vehicles has led to unprecedented number of road traffic accidents, posing a significant threat to the lives and health of the general population. Notably, the lack of effective enforcement of mandatory traffic safety regulations, along with inadequate road safety infrastructure, have made trauma-induced fractures, particularly those resulting from road accidents, a major public health concern in Malawi[19-21].

Among the 67 patients with maxillofacial trauma included in this study, over half (50.75%) were admitted for treatment due to injuries sustained in road accidents. Maxillofacial trauma commonly manifests as either soft tissue damage or fractures. The exposed nature of the maxillofacial region makes it vulnerable to external forces, often leading to fractures that not only affect facial function but can also cause cosmetic deformities. Rapid diagnosis and treatment by clinicians are crucial to minimizing patient suffering and improving outcomes[22]. Clinical symptoms of maxillofacial fractures may vary depending on the location and severity of the injury, typically presenting as swelling, pain, bleeding, displacement, and deformity. For instance, in nasal bone fractures, which are often closed injuries, patients typically experience local pain, soft tissue swelling, or subcutaneous ecchymosis. Deviation of the nasal bridge and depression of the nasal dorsum towards the side of the fracture can occur, and if left untreated, may lead to nasal septum hematoma, subsequent infection, septal abscess, cartilage necrosis, and saddle nose deformity. Additionally, patients with maxillary fractures often present with soft tissue swelling and hematoma without pronounced facial protrusion; facial depression becomes apparent as swelling subsides. When the orbital floor is involved, symptoms such as enophthalmos, diplopia, and decreased visual acuity (i.e., intraocular traumatic changes like lens dislocation and vitreous hemorrhage) may occur. Therefore, delayed diagnosis and treatment of maxillofacial fractures can lead to severe complications and sequelae[23].

Currently, the clinical assessment of fracture patients primarily relies on imaging modalities in addition to physical examination. X-ray, being sensitive to bone density and effective in displaying fractures, serves as a fundamental diagnostic tool. However, its requirement for positional changes during the examination process and the direct impact of positioning accuracy on image quality can exacerbate patient discomfort and complicate the examination. Axial CT scanning addresses some of these limitations. Nevertheless, due to the complex anatomical structure of maxillofacial fractures, plain axial CT scans, while providing comprehensive imaging data from various planes, fail to reveal the three-dimensional structure of the fracture and its relationship with surrounding tissues. As a result, physicians must rely on anatomical knowledge and clinical experience to assess the spatial relationship of maxillofacial fractures, making diagnosis challenging and hindering the formulation of surgical plans[24,25]. To gain a more comprehensive understanding of the overall condition and spatial structure of maxillofacial fractures and reduce medical disputes arising from misdiagnosis or missed diagnoses, the clinical community seeks clearer and more efficient imaging diagnostic methods.

16-slice spiral CT represents a non-invasive imaging technique that boasts a higher scanning speed per unit time, enabling clearer visualization of bones, joints, soft tissues, and blood vessels in the human body. It effectively prevents motion artifacts from compromising image clarity. MSCT acquires raw image data through volumetric scanning, allowing for multi-directional image reconstruction after a single scan, which provides detailed radiological diagnostic information in a short period at reduced radiation doses to ensure patient safety. Additionally, spiral CT boasts robust post-processing capabilities, with 3D reconstruction showcasing fracture locations, displacements, and fracture line orientations from various angles. This eliminates obstruction and interference from other areas, offering an intuitive understanding of the fracture's stereoscopic structure and providing clearer radiological evidence for surgical planning[26]. MPR, a common 3D reconstruction technique in CT, precisely measures fracture fragment displacement and clearly displays surrounding tissue pathology, particularly in deep and intricate maxillofacial structures. Although MPR images can localize fractures in sagittal, coronal, and arbitrary oblique planes, they essentially remain two-dimensional, lacking a sense of depth and overall perspective, particularly for complex spatial anatomical structures. VR images compensate for MPR's limitations by presenting 3D anatomical structures and fracture images of the maxillofacial region with strong spatial and holistic sensations. They allow for comprehensive and detailed observations of fractures through rotations from any angle, clarifying fracture types, spatial relationships between fracture ends and surrounding tissues, and more intuitively displaying temporomandibular joint dislocations. For overlapping structures, VR technique can selectively remove adjacent tissues through cutting, emphasizing critical fracture areas with more realistic and multi-angled 3D imaging, particularly for heavily obscured fractures. When combined with SSD and MIP imaging, MPR and VR technologies offer powerful image processing of CT data, yielding exceptionally clear images of complex maxillofacial fractures, facilitating rapid diagnosis and surgical planning[27-29].

Our findings indicate that among 67 maxillofacial trauma patients, 2D and 3D reconstructions after MSCT scanning provided clear visualization of fractures, surrounding soft tissue injuries, fracture line trajectories, and fracture edge morphologies. Notably, CT 3D reconstruction outperformed conventional CT scans in detecting maxillofacial fractures (80.60% vs. 77.61%, $P > 0.05$). For zygomatic, nasal, and mandibular fractures, MSCT 3D reconstruction images more accurately displayed fracture displacements and trajectories than 2D reconstructions, while 2D cross-sectional images excelled in depicting comminuted fractures involving the sphenoid and ethmoid bones. Such results demonstrated the respective advantages of 2D and three-dimensional 3D CT reconstructions in the assessment of different types of maxillofacial fractures. For fractures of superficial bones like the zygoma and mandible, 3D CT is indispensable for understanding displacement and planning reconstructive procedures, including the use of customized implants. Conversely, 2D CT remains the modality of choice for fractures involving deeply situated, comminuted structures, where slice-by-slice analysis provides clearer delineation. Nonetheless, limitations exist. 3D CT can amplify artifacts or obscure fine details due to rendering complexity, whereas 2D CT may lack the spatial insights critical for certain surgical applications. Future efforts should aim to integrate these modalities with advanced technologies, such as cone-beam CT or augmented reality (AR), to further assist Malawian surgeons in improving diagnostic accuracy and treatment planning.

Conclusion

In summary, the 2D reconstruction technique of MSCT scanning can be used as a basic diagnostic tool for maxillofacial fractures in clinical practice. The 3D CT reconstruction technique, on the other hand, boasts a high detection rate for maxillofacial fractures, enabling accurate visualization of specific fracture conditions from multiple angles and sections. A combined approach, leveraging the strengths of both modalities, is pivotal for comprehensive assessment and management of maxillofacial trauma.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

This study was approved by Mzuzu University Research Ethics Committee (MZUNIREC/DOR/24/153).

Data availability statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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