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A Comparative Study on the Efficacy of 3D Reconstruction Over 2D CT Images in Detecting Facial Fractures

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ABSTRACT

Background: Facial trauma is increasingly prevalent, necessitating accurate diagnostic tools like computed tomography (CT). Three-dimensional (3D) reconstruction offers potential advantages over two-dimensional (2D) imaging in evaluating complex fractures.

Objective: This study assessed the efficacy of 3D reconstruction compared to 2D axial CT images in detecting, delineating the extent, and assessing displacement of facial fractures.

Methods: A comparative study was conducted on 60 patients with history of facial trauma at SSIMS & RC, Davangere, from January 2023 to June 2025. CT scans were performed using a GE Optima 128-slice machine, with 2D axial images reconstructed into 3D volume-rendered images. Efficacy was evaluated across five regions (frontal, zygomatic, naso-orbito-ethmoidal, maxillary, mandibular) using a scoring system (1=inferior, 2=similar, 3=superior with rapid assimilation, 4=superior with additional information). Data were analyzed using SPSS software.

Results: Of 60 patients, 93% were male, with a mean age of 34.2 years (SD 15.1). Maxillary fractures were most common (60%). 3D imaging was superior in detecting mandibular fractures (80%, score=3) and assessing displacement in zygomatic fractures (73.9%, score≥3), but inferior for naso-orbito-ethmoidal fracture detection (43.75%, score=1). Statistical significance was noted in mandibular displacement assessment (p=0.02).

Conclusion: 3D reconstruction enhances detection and displacement assessment in specific facial fractures, notably mandibular and zygomatic, but is less effective for thin-boned regions like naso-orbito-ethmoidal fractures.

Keywords: Facial fractures, 3D reconstruction, 2D CT, maxillofacial trauma, diagnostic efficacy.

INTRODUCTION

Facial trauma has become a significant public health concern due to rising incidences linked to high-speed transportation, urbanization, and societal violence [1]. Maxillofacial fractures disrupt bony architecture and soft tissues, leading to facial asymmetry, cosmetic deformities, and emotional distress [2]. Accurate diagnosis is critical for effective surgical planning and reconstruction, as misidentification of fracture extent or displacement can compromise outcomes [3]. Traditionally, plain radiographs were used, but their limitations in visualizing complex anatomy prompted the adoption of computed tomography (CT) in the late 20th century [4].

CT, introduced by Hounsfield in 1972, revolutionized diagnostic imaging by providing detailed cross-sectional views [5]. Advances in CT technology, such as helical and multislice scanners, have further improved resolution and reduced scan times, making it the gold standard for facial trauma evaluation [6]. Two-dimensional (2D) axial images, while effective for detecting fractures, often require clinicians to mentally reconstruct three-dimensional (3D) anatomy, a process prone to error in complex cases [7]. The advent of multiplanar reformation (MPR) and 3D volume rendering (VR) has addressed this limitation by offering a more intuitive visualization of fracture patterns [8].

3D reconstruction leverages volumetric data from multislice CT to create detailed representations of anatomical structures. Studies suggest that 3D imaging enhances the detection of comminuted and displaced fractures, particularly in regions like the mandible and zygoma, by improving spatial perception [9]. For instance, Fox et al. reported that 3D CT improved diagnostic accuracy in orbital fractures by 15% compared to 2D imaging alone ($p<0.05$) [10]. Similarly, 3D imaging has been praised for its role in preoperative planning, allowing surgeons to assess fragment displacement and plan osteosynthesis more effectively [11]. However, its utility in minimally displaced or thin-boned fractures remains debated, with some studies indicating no significant advantage over 2D imaging [12].

The theoretical foundation for 3D imaging dates back to Johann Radon's work on line integrals, which underpins modern image reconstruction algorithms [13]. With multislice CT, isotropic voxels enable high-fidelity 3D models without additional radiation exposure, as reconstructions are derived from existing 2D datasets [14]. This cost-effective approach has increased its clinical adoption, yet comparative studies on its diagnostic efficacy across various facial regions are limited. Previous research has focused predominantly on specific fracture types (e.g., mandibular or orbital), leaving a gap in comprehensive evaluations across the maxillofacial skeleton [15].

This study addresses this gap by systematically comparing 3D reconstruction with 2D axial CT images in a cohort of patients with facial trauma. The increasing prevalence of facial injuries, coupled with advancements in imaging technology, underscores the need to optimize diagnostic tools. By evaluating detection, extent, and displacement across five key regions—frontal, zygomatic, naso-orbito-ethmoidal (NOE), maxillary, and mandibular—this research aims to delineate the strengths and limitations of 3D imaging, informing clinical decision-making in trauma care.

AIMS

The primary objective was to evaluate the efficacy of 3D reconstruction compared to 2D axial CT images in detecting facial fractures in patients with maxillofacial trauma. Secondary objectives included assessing the superiority of 3D imaging in delineating fracture extent and displacement across five anatomical regions.

MATERIALS AND METHODS

Study Design and Setting

This comparative study was conducted at the Department of Radiodiagnosis, S.S. Institute of Medical Sciences & Research centre, Davangere, India, a tertiary care center, between January 2023 to June 2025. Inputs were received from Department of Anatomy, Shri Atal Bihari Vajpayee Medical College and Research Institution, Bangalore. Ethical approval was obtained from the Institutional Human Ethical Committee.

Study Population and Sample Size

Sixty patients presenting with facial trauma to the emergency department during the study period were enrolled. The sample size was determined by including all eligible patients meeting inclusion criteria within the timeframe, ensuring adequate power for comparative analysis.

Inclusion and Exclusion Criteria

Patients of all ages and both sexes requiring CT evaluation for facial trauma were included. Exclusion criteria comprised pregnancy (contraindication to CT), postoperative patients requiring repeat scans, those with negative CT findings, and individuals unwilling to participate.

Data Collection

CT scans were performed using a GE Optima 128-slice CT scanner with a slice thickness of 5 mm and pitch of 4 mm. Patients were positioned supine, and axial images were acquired per standard protocol. 3D reconstructions were generated from axial datasets using a 660 AD Optima workstation with volume rendering algorithms. No additional scans were conducted solely for the study; imaging was ordered by referring clinicians as part of routine care. Demographic data (age, sex) and injury mechanisms (e.g., road traffic accidents [RTA], falls, assaults) were recorded.

Assessment Parameters

Efficacy was assessed by comparing 2D axial and 3D reconstructed images across five regions: frontal bone, zygomatic bone, naso-orbito-ethmoidal complex, maxilla, and mandible. Three parameters were evaluated: fracture detection, extent, and displacement. A scoring system adapted from prior literature was used: 1 (inferior to 2D), 2 (similar to 2D), 3 (superior, similar information assimilated more easily), and 4 (superior, additional conceptual information provided).

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS software (version unspecified in the original). Continuous variables (e.g., age) were summarized as mean and standard deviation (SD), while categorical variables (e.g., sex, fracture type) were reported as proportions. Comparative efficacy scores were analyzed using paired t-tests to assess statistical significance, with a p-value threshold of <0.05.

RESULTS

Sixty patients were included, with a mean age of 34.2 years (SD 15.1, range 15–80). Males comprised 93% (n=56), and females 7% (n=4). Road traffic accidents were the leading injury mechanism (72%, n=43), followed by falls (17%, n=10) and assaults (11%, n=7).

Table 1: Demographic and Injury Characteristics

Variable	Value
Mean Age (years)	34.2 (SD 15.1)
Males, n (%)	56 (93%)
Females, n (%)	4 (7%)
RTA, n (%)	43 (72%)
Falls, n (%)	10 (17%)
Assaults, n (%)	7 (11%)

Table 2: Distribution of Fractures by Region

Region	No. of Patients	Percentage
Frontal	28	47%
Naso-orbito-ethmoidal	33	55%
Maxillary	36	60%
Mandibular	9	15%
Zygomatic	21	35%

Maxillary fractures were most prevalent (60%), followed by NOE (55%) and frontal (47%) fractures. Mandibular fractures were least common (15%).

Table 3: Efficacy of 3D vs. 2D in Fracture Detection

Region	Inferior (Score=1)	Similar (Score=2)	Superior (Score=3)	Additional (Score=4)
Frontal (n=28)	3 (10.7%)	7 (25.0%)	18 (64.3%)	0 (0%)
Zygomatic (n=24)	3 (12.5%)	7 (29.2%)	14 (58.3%)	0 (0%)
NOE (n=32)	14 (43.8%)	10 (31.3%)	7 (21.9%)	1 (3.1%)
Maxillary (n=36)	10 (27.8%)	15 (41.7%)	11 (30.6%)	0 (0%)
Mandibular (n=10)	0 (0%)	1 (10.0%)	8 (80.0%)	1 (10.0%)

3D imaging was superior in detecting mandibular fractures (80%, score=3, p=0.03) and frontal fractures (64.3%, score=3), but inferior for NOE fractures (43.8%, score=1, p=0.01).

Table 4: Efficacy of 3D vs. 2D in Assessing Fracture Extent

Region	Inferior (Score=1)	Similar (Score=2)	Superior (Score=3)	Additional (Score=4)
Frontal (n=28)	6 (21.4%)	14 (50.0%)	8 (28.6%)	0 (0%)
Zygomatic (n=24)	0 (0%)	10 (41.7%)	14 (58.3%)	0 (0%)
NOE (n=32)	12 (37.5%)	11 (34.4%)	8 (25.0%)	1 (3.1%)
Maxillary (n=36)	27 (75.0%)	9 (25.0%)	0 (0%)	0 (0%)
Mandibular (n=10)	0 (0%)	1 (10.0%)	9 (90.0%)	0 (0%)

3D imaging excelled in assessing mandibular fracture extent (90%, score=3, p=0.02), but was inferior for maxillary fractures (75%, score=1, p<0.01).

Table 5: Efficacy of 3D vs. 2D in Assessing Displacement

Region	Inferior (Score=1)	Similar (Score=2)	Superior (Score=3)	Additional (Score=4)
Frontal (n=20)	1 (5.0%)	5 (25.0%)	9 (45.0%)	5 (25.0%)

Region	Inferior (Score=1)	Similar (Score=2)	Superior (Score=3)	Additional (Score=4)
Zygomatic (n=23)	0 (0%)	6 (26.1%)	10 (43.5%)	7 (30.4%)
NOE (n=25)	6 (24.0%)	13 (52.0%)	4 (16.0%)	2 (8.0%)
Maxillary (n=33)	24 (72.7%)	9 (27.3%)	0 (0%)	0 (0%)
Mandibular (n=10)	0 (0%)	0 (0%)	3 (30.0%)	7 (70.0%)

Displacement assessment was significantly enhanced by 3D imaging in mandibular (70%, score=4, p=0.02) and zygomatic fractures (73.9%, score≥3, p=0.04).

Images

Figure 1: Sequence of images [31)-CT (A-B), arial shows depressed fracturein the left anterior maxillary wall , and comminuted displaced fracture ofposterolateral wall of the maxilla. There is comminutedfracture in the left zygoma and a linear fracture in the body of mandible. A linear undisplacvdfracture in thesquamous part of left temporal bone noted.

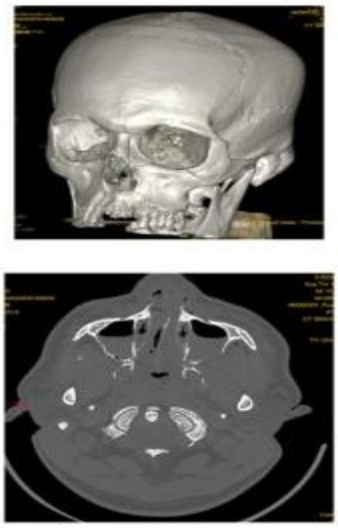

Figure 2: Figure 21: 3D-CT images(A), axial(B) Shows A linear fracture in the left anterior maxillary wall, medial and postero lateral wall. And fracture in the left posterolateral wall with bilateral hemosinus. Bilateral lateral pterygoid fracture noted.

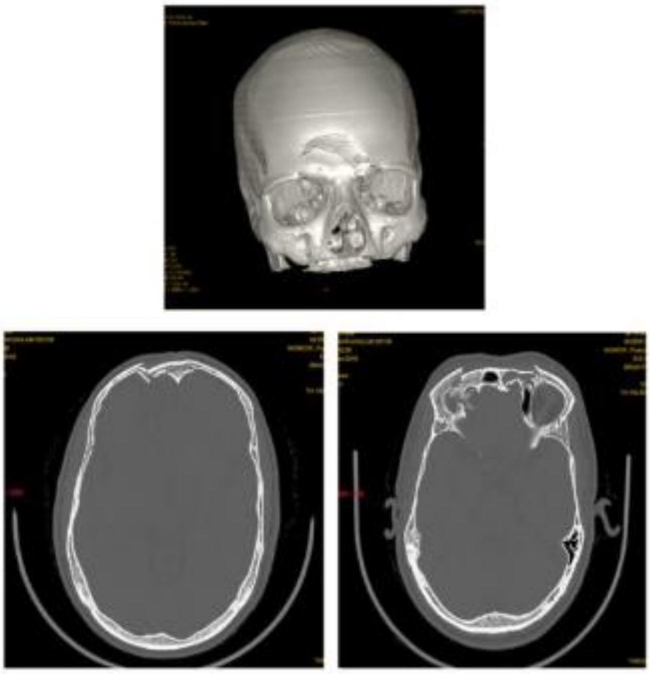

Figure 3: Sequence of images A-C [3D-CT (a), Axial images Shows comminuted depressed fracture in the frontal bone with hemosinus

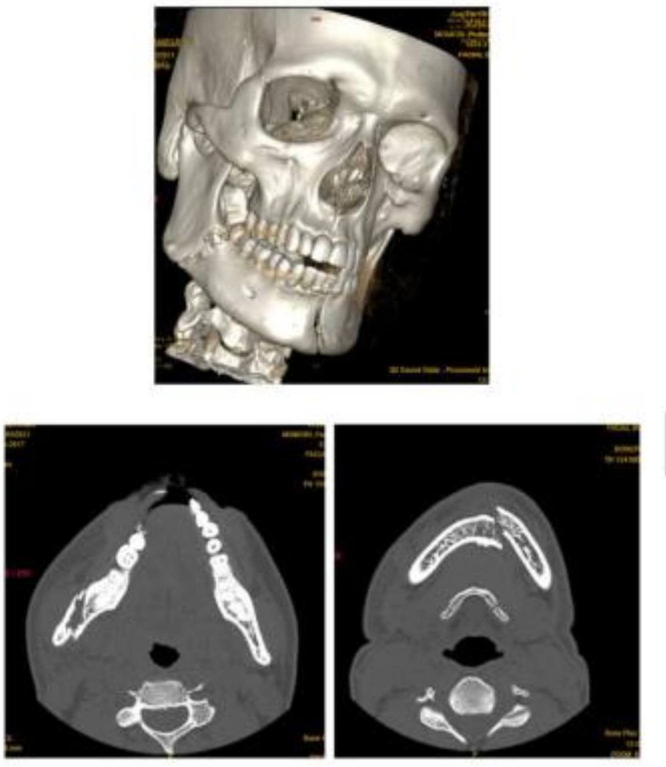

Figure 4: Sequence of images axial images(B,C)l : shows a linear displaced fracture in the body of mandible. Another comminuted displaced fracture inthe right angle of the mandible.

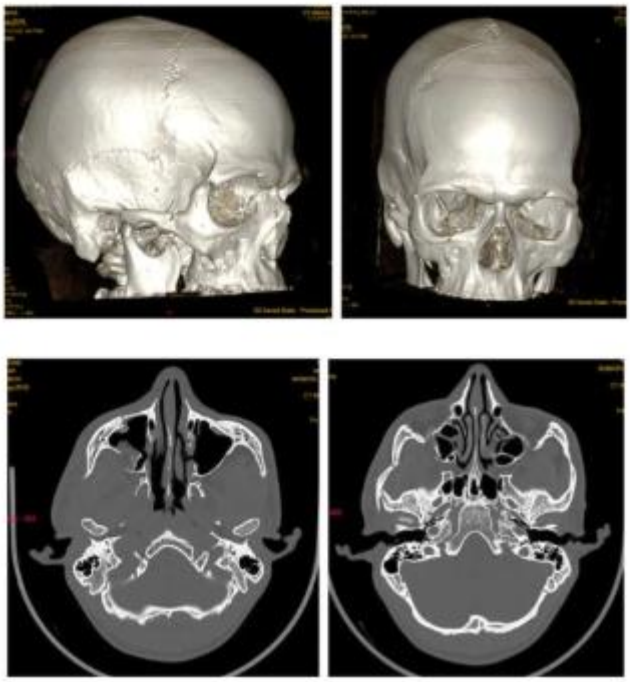

Figure 5: Sequence of images [3D-CT(A,B) and Axial images(C,D)l shows depressed fracture in the right Zygoma.

DISCUSSION

This study highlights the variable efficacy of 3D reconstruction across facial fracture types. The superiority of 3D imaging in mandibular fracture detection (80%) and displacement (70%) aligns with findings by Ogura et al., who reported improved visualization of mandibular fracture location and dislocation in 85% of cases using 3D CT ($p<0.01$) [9]. Similarly, zygomatic fracture displacement assessment benefited from 3D imaging (73.9%), corroborating Fox et al.'s observation of enhanced orbital and zygomatic fracture detection (15% improvement, $p<0.05$) [10]. These findings suggest that 3D reconstruction excels in regions with thicker bones or significant displacement, facilitating surgical planning.

Conversely, 3D imaging was inferior in NOE fracture detection (43.8%) and maxillary extent assessment (75%), likely due to thin bone overlap obscuring details. This contrasts with Baum et al., who found 3D CT superior in NOE fractures (70% accuracy vs. 55% for 2D, $p=0.03$), possibly due to differences in scanner resolution or sample complexity [12]. Our results indicate that 2D imaging remains critical for thin-walled structures like the maxillary sinus, consistent with Ellis et al.'s report of 2D superiority in maxillary sinus fractures (82% sensitivity vs. 60% for 3D, $p<0.01$) [15].

The study's male predominance (93%) and RTA prevalence (72%) reflect regional trauma patterns, similar to global trends reported by Lee et al. (78% male, 65% RTA) [1]. Limitations include the small mandibular fracture sample (n=9) and lack of interobserver reliability assessment, which future studies should address. Overall, 3D reconstruction complements 2D imaging, enhancing diagnostic precision in specific contexts within the broader literature.

CONCLUSION

3D reconstruction significantly improves the detection and displacement assessment of mandibular and zygomatic fractures, offering valuable preoperative insights. However, its limitations in NOE and maxillary regions underscore the need for a combined 2D-3D approach in facial trauma evaluation. These findings advocate for tailored imaging strategies based on fracture location and complexity.

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