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Comparison Between the Efficiency of Cone-Beam Computed Tomography and Conventional Radiography in Diagnosing Different Types of Mandibular Fractures

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Abstract: *Aim* This diagnostic quality and accuracy study is to compare CBCT images and conventional radiographic images in the assessment of different types of mandibular fractures. *Materials and Methods:* The purpose of this study is to demonstrate the importance of cone-beam computed tomography (CBCT) for the accurate diagnosis of mandibular fractures in comparison with conventional imaging. Six patients with varying traumatic injuries that resulted in eleven mandibular fractures were included in this study, all patients were of both sexes and their ages ranged between 5-40 years. All cases were subjected to radiographic imaging using panoramic radiographs and other conventional extra-oral imaging views according to the size and type of fracture and Cone Beam Computed Tomography. Kappa statistic was used, and the significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics Version 20 for windows. (® IBM Corporation, NY, USA. ® SPSS, Inc., an IBM Company). *Results:* for the 3D image site and number of fracture lines, the modality accurately detected all cases. Sensitivity and diagnostic accuracies were 100% and 100%, respectively. Specificity couldn't be computed because there are no negative cases, while for the 2D images sensitivity and diagnostic accuracy for detecting fracture were 81.8% and 81.8% respectively. Sensitivity and diagnostic accuracy for detecting the number of fracture lines were 90.9% and 90.9% respectively. *Conclusion:* CBCT views are the techniques of choice for highlighting the nature of fracture by directly viewing the extent of the fracture, as well as the degree and direction of displacement if present.

Keywords: CBCT, Extraoral Conventional Imaging, Mandibular Fractures, Three-Dimensional Imaging, Panoramic Imaging

1. Introduction

Różyło-Kalinowska I and Aydin et al reported that Maxillofacial trauma includes any physical trauma to the face. Facial trauma can involve soft tissue injuries such as burns, lacerations, and bruises, or fractures of the facial bones such as nasal fractures, jaw fractures, or well-eye injuries [1, 2].

Różyło-Kalinowska I and Alessandrino et al reported that mandibular fracture is a frequent injury because of the mandible's prominence and relative lack of support. As with any facial fracture, consideration must be given to the need for emergency treatment to secure the airway or to obtain homeostasis, if necessary, before initiating definitive treatment of the fracture [1, 3].

Alessandrino et al reported that fractures of the mandible are a common cause of morbidity from trauma. The mandible is the second most frequently fractured bone in the facial skeleton, and in the setting of motor vehicle crashes, mandible fractures are the most frequent. Fractures of the mandible at multiple sites are common and should always be assessed radiographically [3].

Nardi et al and Kihara et al reported explained that radiographic views which are commonly used in cases of mandible fractures include periapical, occlusal mandibular, lateral oblique, reverse Townes' images, posteroanterior, panoramic, and CBCT images [4, 5].

According to all these findings and research the aim of this study was undertaken to compare the diagnostic quality and accuracy of cone-beam computed tomographic images with conventional radiographic images in the assessment of mandibular fractures and with the advent of CBCT as an emerging imaging modality in the dental field, a question always arises; does CBCT provides superior diagnostic capabilities in diagnosing and assessing mandibular trauma in comparison to the commonly used conventional imaging modalities?

2. Methods

2.1. Study Population

This is a Diagnostic Accuracy study that involved six patients with varying traumatic injuries that resulted in eleven mandibular fractures were included in this study. All participants were selected randomly from patients submitted as emergency cases to the outpatient clinics of Nasser Institute and the Imbaba Public Hospital (CAIRO, EGYPT), and the University Hospital of Misr University for Science and Technology (GIZA, EGYPT). All patients were of both sexes and their ages ranged from 5 to 40 years with a mean age of 20 years. Any diagnostic evaluation was delayed until the more life-threatening injuries had been stabilized and treated by the oral surgeon. The study was done in 2012 and the duration of this study was six months.

2.2. Sampling Criteria

Inclusion Criteria were patients with proven mandibular fractures based on the clinical examination.

Exclusion Criteria were patients with contraindications for CBCT scanning of the mandible (e.g., injuries of the cervical spine or severe intracranial injuries), isolated dento-alveolar fractures that were evaluated by panoramic radiography alone, pathological fractures due to pre-existing bone disease, atrophic fractures due to severe atrophy of the bone and patients with life-threatening problems including obstructed airway, profuse hemorrhage, and shock that needed hospitalization.

2.3. Study Design

All the included patients were subjected to the following methods of evaluation:

2.3.1. History Taking

A thorough history was taken with emphasis on the history of trauma using the following printed questionnaire:

1) What was the cause (a mechanism) of injury? (Type and direction of causative traumatic force)
   a) Motor vehicle accidents (MVA) or road traffic accidents (RTA).
   b) Accidental Falls.
   c) Assaults (Fights, altered actions).
   d) Sports injuries.
   e) Gunshot wounds.
   f) Work-related (occupational) injuries.
2) Is there a loss of function? (Cannot bite or chew).
3) Is there any altered sensation? (Are there any areas of numbness on your face along with the distribution of the mental nerve)?
4) After getting the patient to gently close his teeth together, he was asked if the teeth were felt in the correct position or not? (Does your bite feel normal? Do you have any malocclusion? Are you able to bite down without pain?)
5) Have you lost any teeth due to this injury?
6) Are you having any vision changes? (Alterations, partial or complete loss, floaters, double vision).
7) Does it hurt when you open your mouth? Which areas on your face hurt? Does moving the jaw cause pain or spasm?
8) As the jaw moves, is a grinding sound produced?
9) Previous facial fractures.

2.3.2. Clinical Examination

A thorough intra and extra-oral clinical examination were carried out to elicit all the following signs and symptoms using inspection and palpation based on the scheme of [5].

1) Facial asymmetry or misshapen face.
2) Occlusal discrepancies. (Test teeth for stability, assessment of malocclusion i.e., detection of any anterior, posterior, or prognathic open bite as well as inspection for bleeding at the gum line which is a sign of fracture through the alveolar bone) (Figure 1).

Figure 1. *Intra-oral clinical photograph for one of the investigated cases during the examination of occlusion.*

3) Difficulty in opening and closing the mouth or trismus.
4) Areas of paresthesia. (Any changes in sensation and feeling over the face).
5) Extra or intraoral mucosal lacerations, lesions, cut or open wounds.
6) Pain with functional movements of the mandible.
7) Massive edema and ecchymosis (Figure 2) or presence of any eye injury.

Figure 2. *Intra-oral clinical photograph for another case revealing edema at the floor of the mouth and alveolar ecchymosis.*

8) Deviation of the mandible when attempting to open the mouth.

9) Fractured, lost, or missed teeth.
10) Difficulty in talking, breathing, swallowing, or any altered sensation.
11) Persistent bleeding, or edema on the floor of the mouth.
12) Persistent leaking of CSF from the ears.
13) Bimanual palpation of the mandibular contour for crepitus, tenderness, irregularities, discontinuities, swelling, soft tissue depressions or lacerations, and bony step-off (Figure 3).

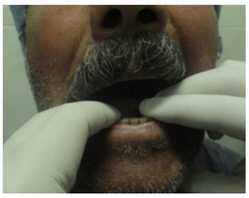

Figure 3. *Clinical photograph during palpation of the mandible for detection of crepitus, tenderness, irregularities, discontinuities, swellings, soft tissue depressions, or bony step-off.*

14) Ears were examined for evidence of lacerations or contusions of the external auditory canal by inserting the fingertip into the canal on one side to determine the movement of the mandible. Inspection of the area just anterior to the meatus of the ear for ecchymosis and palpation for tenderness.

2.3.3. Radiographic Examination

Patients were submitted to the conventional radiographic examination and CBCT scanning. Conventional radiography comprised panoramic imaging for all cases, in addition to one or a combination of the following images lateral-oblique, posteroanterior, and reverse Towne's, according to the anatomic location of the suspected fracture line.

(i). Conventional Radiographic Imaging

1) Panoramic imaging

Patients were exposed to a digital panoramic unit (Ortho-pantomograph OC 200, Instrumentarium Imaging, Helsinki, Finland) using the following parameters: 16 mA, 90 KVP, exposure time: 17.6 seconds, and a focal spot = 0.5 mm. Patient positioning was adjusted electronically using the unit's laser beams for adjustment of the mid-sagittal plane and Frankfurt plane.

2) Posterior-anterior imaging

Patients were exposed to the same digital panoramic unit (Ortho-pantomograph OC 200, Instrumentarium Imaging, Helsinki, Finland) using the following parameters: 13 mA, 90 KVP, exposure time: 2 seconds, and a focal spot = 0.5 mm. Patient positioning was adjusted electronically using the unit's laser beams for adjustment of the mid-sagittal plane and Frankfurt plane.

The patients were positioned so that the Cantho-meatal line formed an 10-degree angle with the horizontal plane. Both the Cantho-meatal line and the Frankfurt planes were set perpendicular to the image detector. The x-ray beam was directed parallel to the patient's mid-sagittal plane and was centered at the level of the bridge of the nose.

3) Reverse Towne's imaging

Patients were exposed to the same digital panoramic unit (Ortho-pantomograph OC 200, Instrumentarium Imaging, Helsinki, Finland) using the following parameters: 13 mA, 80 KVP, exposure time: 2 seconds, and a focal spot = 0.5 mm. Patient positioning was adjusted electronically using the unit's laser beams for adjustment of the mid-sagittal plane and Frankfurt plane.

The patients were positioned so that the image receptor was placed in front of the patient perpendicular to the mid-sagittal plane and parallel to the coronal plane. The patient's head was tilted downward so that the Cantho-meatal line formed a 25–30-degree angle with the image receptor with the patient's mouth in the open position.

4) Lateral oblique imaging

Patients were exposed by an x-ray unit (Orix 70 A.C. ARDET. Dental & Medical Devices S.r.l. Apparecchi Radiologici per Diagnostica & Terapia, Italy). Ultra-speed dental films (Kodak products, USA) were used to produce the lateral –oblique images. The exposure parameters used were 70 kV, 13 mA, and 2 seconds exposure time. Films were processed by an automatic processor (Kodak products, USA). Images were digitized using a digital camera (Canon, EOS350D, Digital camera 8.0 Megapixels, Japan).

For producing lateral-oblique images, the cassette was placed against the patient's cheek on the side of interest and centered in the molar-premolar area. The lower border of the cassette was parallel and at least 2 cm below the inferior border of the mandible. The head was tilted towards the examined side, and the mandible protruded. The central beam was directed towards the molar-premolar region from a point 2cm from the angle of the opposite side of the mandible.

(ii). CBCT Imaging

CBCT Scanning Protocol

All patients were submitted to CBCT scanning using a Scanora 3D cone beam system (Scanora 3D, Soredex, Helsinki, Finland) with a CMOS flat panel image detector with isotropic voxel size 133Um.

The patients were exposed in the sitting position. The seat height was adjusted to position the region of interest (ROI) vertically within the field of view (FOV). FOV adjustment was guided by laser light beams to centralize the area of interest within the scanning field. An upper light beam indicated the top of the FOV, and another lower light beam indicated the bottom of the FOV. A vertical frontal light beam was positioned in the center of the FOV from the sagittal. Another lateral vertical light was positioned in the center of the FOV in the lateral plane.

The patients were asked to remove metallic objects or appliances in the exposure area. All patients were instructed not to move during the duration of exposure. Images were obtained at the following exposure parameters; 15 mA, 85 KV, and a focal spot size of 0.5 mm. The scanning time was 12 seconds of pulsed exposure resulting in an effective exposure time of 3.5 seconds to scan a field of view (FOV) 6 x 6 x 6 cm in the anterior region, using a slice thickness of 0.5 mm.

The primary reconstruction time for the DICOM data was set at 2 minutes. The raw data obtained from the CBCT scanning were imported to the OnDemand 3D software for secondary reconstruction (OnDemand3D version 1.0.9, Cybermed, Seoul, South Korea).

Data Acquisition

After exposure, a preview image appears on the Clear Touch-TM control panel. The user can easily verify that imaging has been successful. Once the preview image has been accepted, the 3D image set appears for examination and diagnosis on the workstation. The 3D display shows axial, cross-sectional, panoramic, and custom slices (Figure 4).

Image Reconstruction

Cross-sectional reconstructions were created by reformatting the axial scans on a local workstation using the Scanora 3D dental imaging software following the manufacturer's instructions. The software automatically generates cross-sectional views after a centerline is drawn along the jaw. No time-consuming reformatting is needed (Figure 4), (Figure 5), (Figure 6), and (Figure 7).

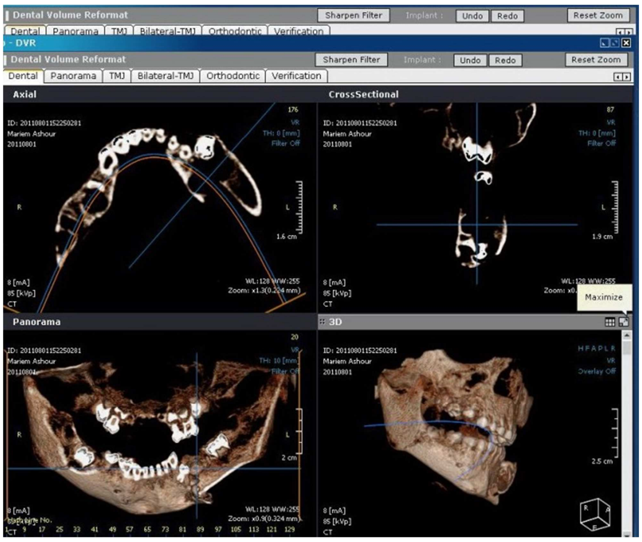

Figure 4. *The display screen of the 3DScanora unit demonstrates an axial image, cross-sectional view, 3D views, and a reformatted panoramic view.*

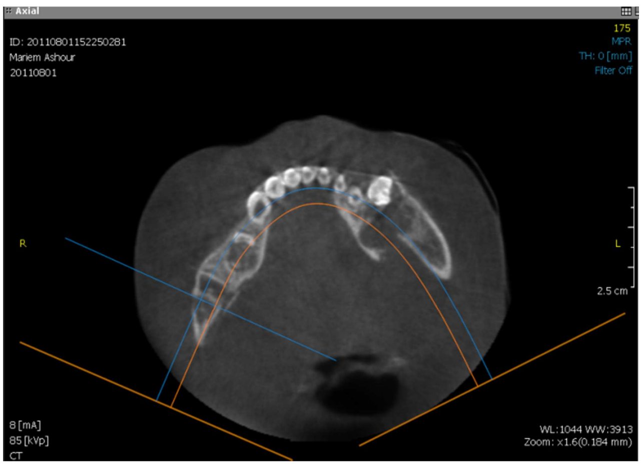

Figure 5. *Reformatting of the axial cut on a local workstation using the 3D scaonra software.*

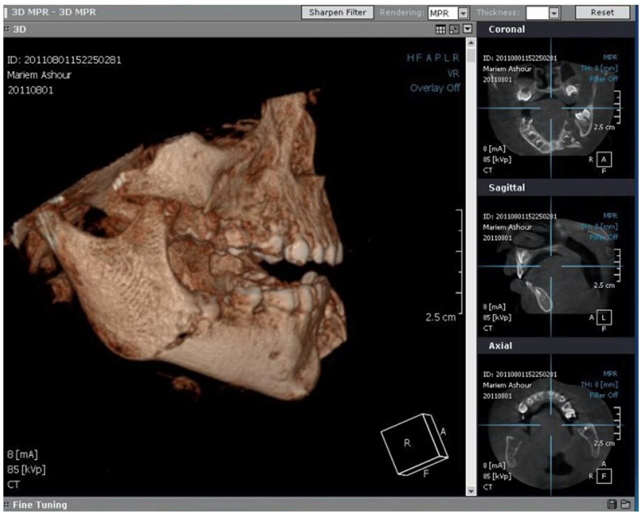

Figure 6. *The MPR screen of the 3DScanora unit demonstrating axial, coronal, sagittal, and 3D views.*

Figure 7. *Reformatted panoramic image generated by the CBCT unit.*

Image analysis

To eliminate the inter-observer errors, the CBCT and conventional images were independently and separately blindly assessed by three radiologists at two different sessions.

Each radiologist performed the assessment twice at two different times with a 2-weeks interval period in between as an attempt to eliminate the intra-observer errors. Inter and intra-observer variability tests were performed on the original data to reveal the degree of agreement between the recorded data. If the evaluation differed between the three examiners, the images were rechecked until a consistent result was obtained to be included in further statistical analysis.

The surgical observation was the gold standard corroborating the diagnosis of mandibular fracture, its anatomic location, number of fracture lines, the occurrence of comminution, displacement of bone structures, and effect on teeth and IAC.

The obtained data and images were used to assess the mandibular fractures for the following: (The original data were transferred to a data worksheet summarizing the identified clinical and radiographic findings; these sheets were completed for all investigated cases).

1. Presence or absence of fracture
2. Location of fracture lines (anatomical localization).
3. Presence of displacement and step formation.
4. Size and number of fracture lines.
5. Areas of comminution.
6. Effect on teeth.

7. Effect on IAC.

Scoring system for radiographic data

1. Presence or absence of fracture
   1) Negative……………………………………….………0
   2) Positive……………………………………….…..…1
   3) Uncertain…………………………………………... 2
2. Location of fracture lines (anatomical localization).
   1) Body………………………………………..……… 1
   2) Angle…………………………………………..…... 2
   3) Symphyseal – Para symphyseal………………….... 3
   4) Ramus…………………………………………….... 4
   5) Condyle / sub-condyle…………………………...... 5
   6) Coronoid……………………………………..….… 6
   7) Associated alveolar fracture…………………….... 7
3. Number of fracture lines.
   1) Negative ……………………………………..…… 0
   2) Positive ……………………………………….…… 1
   3) Uncertain…………………………………………... 2
4. Presence of displacement and step formation.
   1) Negative …………………………………………... 0
   2) Positive …………………………………………… 1
   3) Uncertain…………………………………………... 2
5. Areas of comminution.
   1) Negative …………………………………………... 0
   2) Positive ……………………………………….…… 1
   3) Uncertain…………………………………………... 2
6. Effect on teeth.
   1) Negative …………………………………………... 0
   2) Positive …………………………………..…….….. 1
   3) Uncertain……………………………………….…… 2
7. Effect on IAC.
   1) Negative …………………………………………... 0
   2) Positive ………………………………………….… 1
   3) Uncertain…………………………………………... 2

2.4. Statistical Analysis

Qualitative data were presented as frequencies and percentages. Chi-square (x^2) test was used for studying the comparisons and associations between different variables.

Sensitivity, Specificity, and Diagnostic accuracy were calculated as follows:

$$\text{Sensitivity (\%)} = \frac{\text{True positive}}{\text{True positive + False negative}} \text{ x } 100$$

$$\text{Specificity (\%)} = \frac{\text{True negative}}{\text{False positive + True negative}} \text{ x } 100$$

$$\text{Diagnostic accuracy (\%)} = \frac{\text{True positive + True negative}}{\text{Total number}} \text{ x } 100$$

An increase in sensitivity means a decrease in false-negative cases, while an increase in specificity means a decrease in false-positive cases.

Kappa statistic was used to measure the agreement between the evaluations of the different raters (observers). A value of 1 indicates perfect agreement. Kappa values can be interpreted as follows: poor (<0.2), fair (0.21 – 0.4), moderate (0.41 – 0.6), good (0.61 – 0.8) and very good (0.81 – 1.00).

The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM SPSS Statistics Version 20 for windows. (® IBM Corporation, NY, USA. ® SPSS, Inc., an IBM Company).

3. Results

This study comprised a total of eleven mandibular fractures sustained from six patients subjected to varying traumatic injuries. All patients were of both sexes and their ages ranged between 5-40 years with a mean age of 20 years. The distribution of fractures according to the ages of the patients and cause of trauma are presented in “Table 1”. The distribution of the subjective results of history taking and clinical examination are presented in “Table 2”.

The mandibular fractures in the current work were distributed among the included cases in varying degrees. Symphyseal fracture comprised 9% of the cases (1 case), the para-symphyseal fracture was detected in 27.2% of the cases (3 cases), while body fracture was seen in 18.1% of the cases (2 cases). Angle fracture and sub-condylar fracture presented 18.1%; of the cases (2 cases each). Finally, greenstick fracture was detected in only one case (9% of all cases).

All cases were subjected to extensive history taking, thorough physical examination, and radiographic imaging using CBCT and conventional radiography (CR). CR comprised panoramic imaging for all cases, posteroanterior, reverse Towne’s, and lateral oblique views which were done whenever needed according to the anatomic location of the investigated fracture.

The results of image analysis performed by the three observers according to the evaluation of image quality were graded as present (+ve), absent (-ve) or uncertain. This grading was according to the ease of interpretation of each image regarding the tested features related to the existing fracture.

Comparative analysis was performed between the data given by the three observers after interpreting the CBCT and CR images to reveal differences between the two modalities regarding detection (presence) of fractures, localization of fractures (site), assessment of the number of fracture lines, displacement, comminution, effect on teeth, and effect on the inferior alveolar canal (IAC). The significant level was set at *P ≤ 0.05.*

Diagnostic accuracy, sensitivity, and specificity of the tested modalities were calculated regarding their validity in detection (presence) of fractures, localization of fractures (site), an assessment of the number of fracture lines, displacement, comminution, effect on teeth, and effect on the inferior alveolar canal (IAC).

Table 1. *Distribution of the investigated fractures according to the cause of trauma and age of injured patients.*

Case Number	Age (Years)	Etiology
Fracture (1)	6	Falling from the third floor.
Fracture (2)	6	Falling from the third floor.
Fracture (3)	22	Assaults fighting altercations (Blunt force)
Fracture (4)	4.5	Falling from the second floor.
Fracture (5)	4.5	Falling from the second floor.
Fracture (6)	5	Accidental motorcycle.
Fracture (7)	5	Accidental motorcycle.
Fracture (8)	40	Occupational injury.
Fracture (9)	40	Occupational injury.
Fracture (10)	19	Assaults fighting altercations (Blunt force)
Fracture (11)	19	Assaults fighting altercations (Blunt force)

From the previous table, it could be noticed that falling from high floors was the etiologic factor for the injury in 36.3% of the cases (4 cases), fights represented 27.2% (3 cases), accidental motorcycle and occupational injuries represented 18.1%; each, (2 cases each) of the cause of fracture.

Table 2. *Distribution of the data from history taking and clinical findings among the investigated cases.*

Case Number	History Data	Clinical Finding/s
Fracture (1) Case 1	Difficulty in biting and injuries in the face.	Facial asymmetry, lacerations in the face with pain in mandibular movement.
Fracture (2) Case 1	Difficulty in biting and injuries in the face.	Facial asymmetry, lacerations in the face with pain in mandibular movement.
Fracture (3) Case 2	Numbness in the face.	Edema in the site of fracture.
Fracture (4) Case 3	In juried face, can't chew and bite is not at the correct position.	Facial asymmetry with deviation in mandible during the opening with pain during the opening.
Fracture (5) Case 3	Injured face, can't chew, and the bite is not at the correct position.	Facial asymmetry with deviation in mandible during the opening with pain during the opening.
Fracture (6) Case 4	Injury in the face with difficulty in opening his mouth.	Facial asymmetry, lacerations, difficulty in opening the mandible, and malocclusion.
Fracture (7) Case 4	Injury in the face with difficulty in opening his mouth.	Facial asymmetry, lacerations, difficulty in opening the mandible, and malocclusion.
Fracture (8) Case 5	Numbness and difficulty in opening moth with mal occlusion.	Deviation of fractured part of mandible and mal occlusion.
Fracture (9) Case 5	Numbness and difficulty in opening moth with mal occlusion.	Deviation of fractured part of mandible and mal occlusion.
Fracture (10) Case 6	Can't bite and his jaw produces grinding sound.	Pain during movement of the mandible with edema in the fractured site.
Fracture (11) Case 6	Can't bite and his jaw produces grinding sound.	Pain during movement of the mandible with edema in the fractured site.

From the previous table and upon analyzing the data collected from history taking, it could be shown that difficulty in biting and facial injuries presented the highest complaints among all patients (6 cases representing 54.5%), and difficulty in the opening mouth was reported by 4 cases of the investigated patients representing 36.3%. Numbness was reported in 3 cases representing 27.2%. Finally, malocclusion and grinding sounds were reported in 2 cases respectively: representing 18.1% each.

From the previous table and upon analyzing the clinical findings, the following results could be noticed; lacerations and edema presented the highest incidence among the findings revealed upon physical examination of the patients (7 cases representing 63.6%), this was followed by equal distribution of the remaining three clinical findings; facial asymmetry, deviation and mal-occlusion, and pain during function (each seen in 6 cases representing 54.5% each).

Comparisons between Image Quality of CBCT and Conventional Radiography

1. Detection of Fracture

There was a statistically significant difference between the different modalities. Axial, cross-sectional, reconstructed panoramic image, 3D and reverse Towne's modalities enabled observers to detect the presence of fracture in all cases.

PA modality didn't reveal fractures. Negative detection of fracture was also found with 2D panoramic and lateral oblique modalities. 2D panoramic imaging was the only modality that showed an uncertain diagnosis (Table 3 and figure 8).

Table 3. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting fractures.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	11	100	<0.001*
	Negative	0	0	
	Uncertain	0	0	
Cross-sectional	Positive	11	100	
	Negative	0	0	
	Uncertain	0	0	
Reconstructed panorama	Positive	11	100	
	Negative	0	0	
	Uncertain	0	0	
3D	Positive	11	100	
	Negative	0	0	
	Uncertain	0	0	
2D Panoramic	Positive	9	77.8	
	Negative	1	11.1	
	Uncertain	1	11.1	
Lateral oblique	Positive	1	33.3	
	Negative	2	66.7	
	Uncertain	0	0	
Reverse Town	Positive	1	100	
	Negative	0	0	
	Uncertain	0	0	
PA	Positive	0	0	
	Negative	1	100	
	Uncertain	0	0	

*: Significant at P ≤ 0.05.

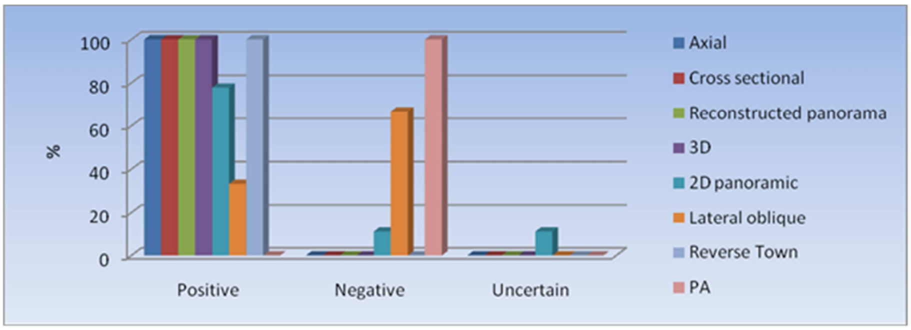

Figure 8 *Detection of fracture with the different modalities.*

2. Site

There was a statistically significant difference between the different modalities. Axial, cross-sectional reconstructed panoramic imaging, 3D, and Reverse Towne's modalities accurately detected sites of fracture in all cases in comparison to the gold standard results.

PA modality didn't detect any fracture. Negative results were also found with 2D panoramic and lateral oblique modalities. 2D panoramic imaging was the only modality that showed an uncertain diagnosis (Table 4 and figure 9).

Table 4. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting sites of fracture.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	11	100	<0.001*
	Negative	0	0	
	Uncertain	0	0	
Cross-sectional	Positive	11	100	
	Negative	0	0	
	Uncertain	0	0	
Reconstructed panorama	Positive	11	100	
	Negative	0	0	
	Uncertain	0	0	
3D	Positive	11	100	
	Negative	0	0	
	Uncertain	0	0	
2D Panoramic	Positive	9	77.8	
	Negative	1	11.1	
	Uncertain	1	11.1	

Modality	Score	Frequency	%	*P*-value
	Positive	1	33.3	
Lateral oblique	Negative	2	66.7	
	Uncertain	0	0	
	Positive	1	100	
Reverse Town	Negative	0	0	
	Uncertain	0	0	
	Positive	0	0	
PA	Negative	1	100	
	Uncertain	0	0	

*: Significant at P ≤ 0.05.

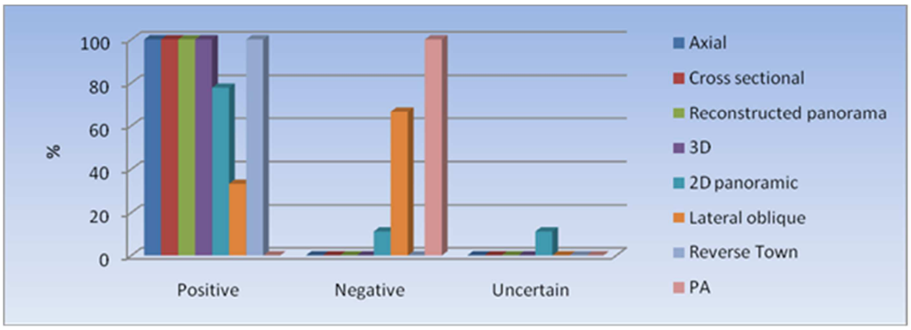

Figure 9. *Site of fracture with the different modalities.*

3. Number of fracture lines

There was a statistically significant difference between the different modalities. Axial, cross-sectional reconstructed panoramic images, 3D, and reverse Towne's modalities accurately detected the number of fracture lines in all cases. PA modality didn't accurately detect the number of fracture lines. Negative results were also found with 2D panoramic and lateral oblique modalities (Table 5 and figure 10).

Table 5. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting the number of fracture lines.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	11	100	
	Negative	0	0	
Cross-sectional	Positive	11	100	
	Negative	0	0	
Reconstructed panorama	Positive	11	100	
	Negative	0	0	
3D	Positive	11	100	
	Negative	0	0	
2D Panoramic	Positive	8	88.9	<0.001*
	Negative	3	11.1	
Lateral oblique	Positive	1	33.3	
	Negative	2	66.7	
Reverse Town	Positive	1	100	
	Negative	0	0	
PA	Positive	0	0	
	Negative	1	100	

*: Significant at P ≤ 0.05.

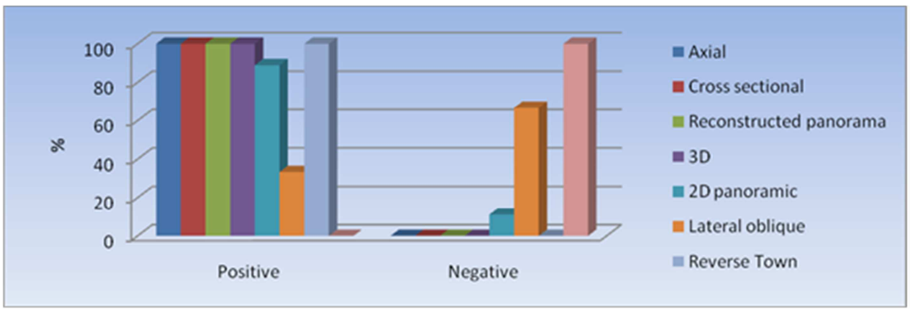

Figure 10. *Number of fracture lines with the different modalities.*

4. Displacement

There was no statistically significant difference between the different modalities in revealing the presence of displacement and step formation (Table 6 and figure 11).

Table 6. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting displacement.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	7	63.6	0.387
	Negative	4	36.4	
Cross-sectional	Positive	5	45.5	
	Negative	6	54.5	
Reconstructed panorama	Positive	7	63.6	
	Negative	4	36.4	
3D	Positive	7	63.6	
	Negative	4	36.4	
2D Panoramic	Positive	4	44.4	
	Negative	7	55.6	
Lateral oblique	Positive	0	0	
	Negative	3	100	
Reverse Town	Positive	1	100	
	Negative	0	0	
PA	Positive	0	0	
	Negative	1	100	

*: Significant at P ≤ 0.05.

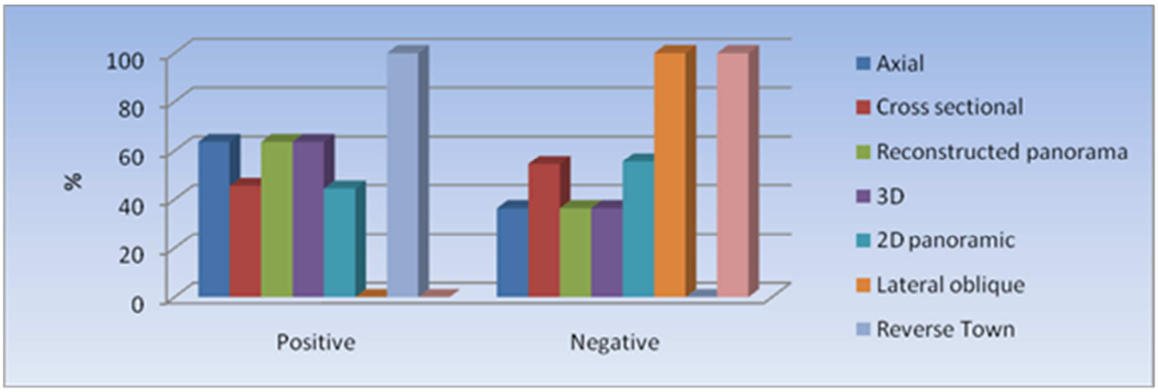

Figure 11. *Detection of displacement with the different modalities.*

5. Comminutions

There was no statistically significant difference between the different modalities in demonstrating any comminution (Table 7 and figure 12).

Table 7. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting comminutions.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	4	36.4	0.226
	Negative	7	63.6	
Cross-sectional	Positive	4	36.4	
	Negative	7	63.6	
Reconstructed panorama	Positive	3	27.3	
	Negative	8	72.7	
3D	Positive	7	63.6	
	Negative	4	36.4	
2D Panoramic	Positive	1	11.1	
	Negative	10	88.9	
Lateral oblique	Positive	0	0	
	Negative	3	100	
Reverse Town	Positive	0	0	
	Negative	1	100	
PA	Positive	0	0	
	Negative	1	100	

*: Significant at P ≤ 0.05.

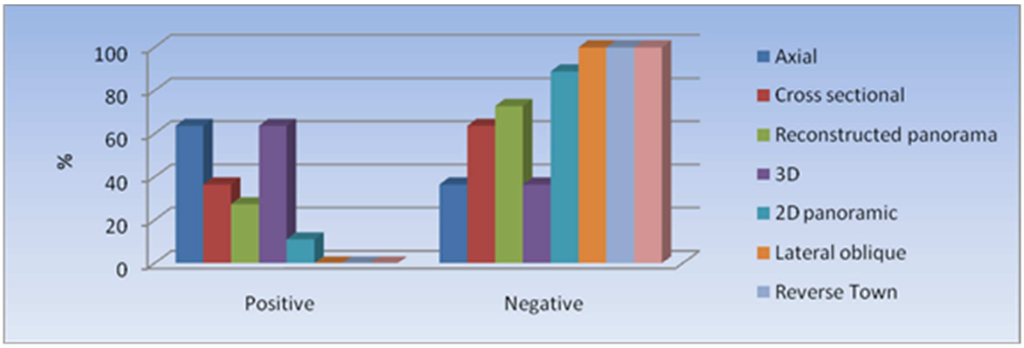

Figure 12. *Detection of comminutions with the different modalities.*

6. Effect on teeth

There was no statistically significant difference between the different modalities in detecting the effect of the injury on the teeth (Table 8 and figure 13).

Table 8. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting effect on teeth.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	6	54.5	0.411
	Negative	5	45.5	
Cross-sectional	Positive	5	45.5	
	Negative	6	54.5	
Reconstructed panorama	Positive	6	54.5	
	Negative	5	45.5	
3D	Positive	6	54.5	
	Negative	5	45.5	
2D Panoramic	Positive	2	22.2	
	Negative	9	77.8	
Lateral oblique	Positive	0	0	
	Negative	3	100	
Reverse Town	Positive	0	0	
	Negative	1	100	
PA	Positive	0	0	
	Negative	1	100	

*: Significant at $P \leq 0.05$.

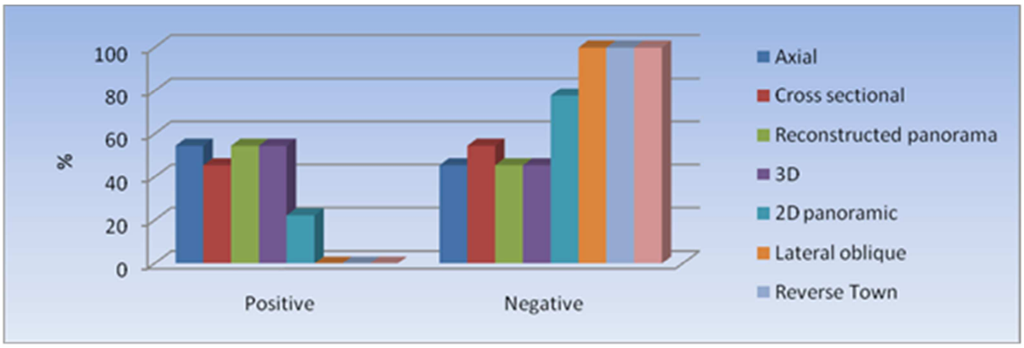

Figure 13. *Detection of effect on teeth with the different modalities.*

7. Effect on IAC

There was no statistically significant difference between the different modalities in revealing the effect of trauma on the IAC (Table 9 and figure 14).

Table 9. *The frequencies, percentages, and results of the chi-square test for the comparison between the different modalities in detecting effect on IAC.*

Modality	Score	Frequency	%	*P*-value
Axial	Positive	5	45.5	0.205
	Negative	6	54.5	
Cross-sectional	Positive	5	45.5	
	Negative	6	54.5	

Modality	Score	Frequency	%	*P*-value
Reconstructed panorama	Positive	5	45.5	
	Negative	6	54.5	
3D	Positive	5	45.5	
	Negative	6	54.5	
2D Panoramic	Positive	0	0	
	Negative	11	100	
Lateral oblique	Positive	0	0	
	Negative	3	100	
Reverse Town	Positive	0	0	
	Negative	1	100	
PA	Positive	0	0	
	Negative	1	100	

*: Significant at $P \leq 0.05$.

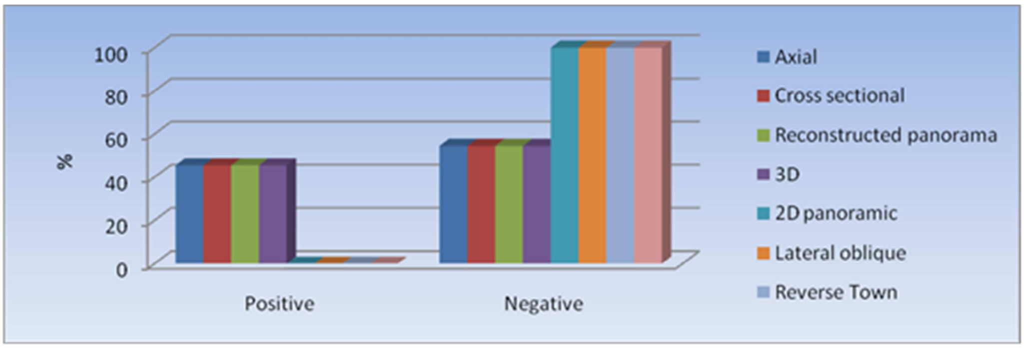

Figure 14. *Detection of effect on IAC with the different modalities.*

8. Accuracy Measures

The “Gold Standard” for the current work was the results of the surgical intervention as well as the clinical diagnosis. The specificity could not be estimated because the diagnosis of the true negative was not confirmed since surgical intervention occurred only for suspected fractures. Also, for the same reason, no accuracy measures were calculated for displacement, comminutions, and effect on teeth and IAC.

1) Axial view

As regards detection, site, and number of fracture lines, the modality accurately detected all cases. So, sensitivity and diagnostic accuracies were 100% and 100%, respectively. Specificity couldn’t be computed because there are no negative cases.

2) Cross-sectional view

As regards detection, site, and number of fracture lines, the modality accurately detected all cases. So, sensitivity and diagnostic accuracies were 100% and 100%, respectively. Specificity couldn’t be computed because there are no negative cases.

3) Reconstructed panoramic view

As regards detection, site, and number of fracture lines, the modality accurately detected all cases. So, sensitivity and diagnostic accuracies were 100% and 100%, respectively. Specificity couldn’t be computed because there are no negative cases.

4) 3D image

As regards detection, site, and number of fracture lines, the modality accurately detected all cases. So, sensitivity and diagnostic accuracies were 100% and 100%, respectively. Specificity couldn’t be computed because there are no negative cases.

5) 2D panoramic view

Sensitivity and diagnostic accuracy for detecting fracture were *81.8%* and *81.8%* respectively. Sensitivity and diagnostic accuracy for detecting the number of fracture lines were *90.9%* and *90.9%* respectively. Uncertain cases were considered as negative to calculate the accuracy measures.

Table 10. *Sensitivity, specificity, and diagnostic accuracy of 2D panoramic view in detecting fracture.*

Modality	Diagnosis		Total
	+ ve	- ve	
+ ve	9 (True +ve)	0 (False +ve)	9
- ve	2 (False –ve)	0 (True –ve)	2
Total	11	0	11

Sensitivity (%) = $\frac{9}{9+2} x\ 100$ = 81.8%

Specificity (%) = $\frac{0}{0+0} x\ 100$ = Not computed

Diagnostic accuracy (%) = $\frac{9+0}{11} x\ 100$ = 81.8%

Table 11. *Sensitivity, specificity, and diagnostic accuracy of 2D panoramic view in detecting site of fracture.*

Modality	Diagnosis		Total
	+ ve	- ve	
+ ve	9 (True +ve)	0 (False +ve)	9
- ve	2 (False –ve)	0 (True –ve)	2
Total	11	0	11

Sensitivity (%) = $\frac{9}{9+2} x\ 100$ = 81.8%

Specificity (%) = $\frac{0}{0+0} x\ 100$ = Not computed

Diagnostic accuracy (%) = $\frac{9+0}{11} x\ 100$ = 81.8%

***Table 12.** Sensitivity, specificity, and diagnostic accuracy of 2D panoramic view in detecting the number of fracture lines.*

Modality	Diagnosis		Total
	+ ve	- ve	
+ ve	10 (True +ve)	0 (False +ve)	10
- ve	1 (False –ve)	0 (True –ve)	1
Total	11	0	11

Sensitivity (%) = $\frac{10}{10+1}$ *x 100* = 90.9%

Specificity (%) = $\frac{0}{0+0}$ *x 100* = Not computed

Diagnostic accuracy (%) = $\frac{10+0}{11}$ *x 100* = 90.9%

6) Lateral oblique view

Sensitivity and diagnostic accuracy for detecting fracture were 33.3% and 33.3%, respectively. Sensitivity and diagnostic accuracy for detecting the site of fracture were 33.3% and 33.3, respectively. Sensitivity and diagnostic accuracy for detecting the number of fracture lines were 33.3% and 33.3, respectively.

***Table 13.** Sensitivity, specificity, and diagnostic accuracy of lateral oblique view in detecting fracture.*

Modality	Diagnosis		Total
	+ ve	- ve	
+ ve	1 (True +ve)	0 (False +ve)	1
- ve	2 (False –ve)	0 (True –ve)	2
Total	3	0	3

Sensitivity (%) = $\frac{1}{1+2}$ *x 100* = 33.3%

Specificity (%) = $\frac{0}{0+0}$ *x 100* = Not computed

Diagnostic accuracy (%) = $\frac{1+0}{3}$ *x 100* = 33.3%

***Table 14.** Sensitivity, specificity, and diagnostic accuracy of 2D panoramic view in detecting site of fracture.*

Modality	Diagnosis		Total
	+ ve	- ve	
+ ve	1 (True +ve)	0 (False +ve)	1
- ve	2 (False –ve)	0 (True –ve)	2
Total	3	0	3

Sensitivity (%) = $\frac{1}{1+2}$ *x 100* = 33.3%

Specificity (%) = $\frac{0}{0+0}$ *x 100* = Not computed

Diagnostic accuracy (%) = $\frac{1+0}{3}$ *x 100* = 33.3%

***Table 15.** Sensitivity, specificity, and diagnostic accuracy of 2D panoramic view in detecting the number of fracture lines.*

Modality	Diagnosis		Total
	+ ve	- ve	
+ ve	1 (True +ve)	0 (False +ve)	1
- ve	2 (False –ve)	0 (True –ve)	2
Total	3	0	3

Sensitivity (%) = $\frac{1}{1+2}$ *x 100* = 33.3%

Specificity (%) = $\frac{0}{0+0}$ *x 100* = Not computed

Diagnostic accuracy (%) = $\frac{1+0}{3}$ *x 100* = 33.3%

7) Reverse Towne's view

As regards detection, site, and number of fracture lines, the modality accurately detected all cases. So, sensitivity and diagnostic accuracies were 100% and 100%, respectively. Specificity couldn't be computed because there are no negative cases.

8) PA view

This modality didn't accurately detect fracture, site of the fracture, and the number of fracture lines. So, sensitivity and diagnostic accuracies were 0% and 0%, respectively.

9) Inter-observer agreement

There was perfect agreement between the three observers regarding all parameters except for the following:

10) Reconstructed panoramic view

There was perfect agreement between the three observers regarding all parameters except for the effect on teeth where the Kappa value for the agreement between observer 1 and observer 3 was 0.865 and it was 0.865 between observer 2 and observer 3.

11) 2D panoramic view

There was perfect agreement between the three observers regarding all parameters except for detecting fracture and detecting the site of fracture where the Kappa value for the agreement between observer 1 and observer 2 was 0.865 and it was 0.865 between observer 1 and observer 3.

***Table 16.** Results of Kappa statistic for the inter-observer agreement in detecting effect on teeth with Reconstructed panoramic view.*

Observer 1 Vs. Observer 2	Observer 1 Vs. Observer 3	Observer 2 Vs. Observer 3
Kappa value	Kappa value	Kappa value
1.000	0.865	0.865

***Table 17.** Results of Kappa statistic for the inter-observer agreement in detecting fracture with 2D panoramic view.*

Observer 1 Vs. Observer 2	Observer 1 Vs. Observer 3	Observer 2 Vs. Observer 3
Kappa value	Kappa value	Kappa value
0.865	0.865	1.000

***Table 18.** Results of Kappa statistic for the inter-observer agreement in detecting the site of fracture with 2D panoramic view.*

Observer 1 Vs. Observer 2	Observer 1 Vs. Observer 3	Observer 2 Vs. Observer 3
Kappa value	Kappa value	Kappa value
0.865	0.865	1.000

4. Discussion

4.1. Discussion of Methodology

Aydin et al stated that the mandible is the second most fractured bone in the facial skeleton because of its prominence and its relative lack of support. They also added that this area of the fracture causes morbidity from trauma [2].

Weiss stated that trauma is considered the fourth major cause of mortality in some countries, of which almost one-half involve maxillofacial injury [7].

Nardi et al confirmed that diagnosis of mandibular fracture is considered an integral part of the secondary survey of any "Emergency Department Care" and should also be kept in mind when evaluating the airway during any primary survey [4].

That's why we followed the previous recommendations in the current work to throw light on the most sensitive imaging modality in assessing mandibular fractures.

Diagnosis of mandibular trauma is obvious with a gross deformity or displacement, but in other cases, a fracture may be suggested only by the history and clinical examination.

That's why in the current work, thorough history taking to clear out the events surrounding the injury was performed using a previously established questionnaire. The etiology of trauma was also recorded in this work because according to Kumaravel it could provide clues to the type of fractures the patient could have [8].

This scheme was approved in many types of research as those by Kumaravel, Karjodkar, Gözler S and Cho GL [8-11].

Sebaey et al stated that in facial trauma, imaging provides information that is known to contribute to accurate diagnosis and greater understanding of the degree and extent of the injury. Ideally, this should be reflected in reduced operating times, reduction in post-operative complications, shorter hospital stays, and improved clinical results [12].

Alessandrino et al, Nardi et al 2020 and Nardi et al 2018 stated that radiography plays a crucial role in the diagnosis and management of traumatic injuries, so the choice of diagnostic radiographs must be based on the ability of each radiograph to evaluate the type and site of each fracture [3, 4, 6].

That's why this study was based on imaging each patient with two different imaging modalities; two-dimensional and three-dimensional imaging to compare the diagnostic accuracy of both tools to highlight the most effective diagnostic images in the assessment of mandibular fracture.

Różyło-Kalinowska I reported that the best plain radiograph to assess the mandible is a panoramic view as it shows the entire mandible in a single view which is adequate for the detection of uncomplicated mandibular fractures, only if patient positioning and choice of exposure parameters are adequate [1].

Watanabe et al stated that one of the primary techniques applied in "Emergency Medicine" for the evaluation of mandibular injuries is panoramic radiography. Following all these recommendations, panoramic images were included in the current work as one of the investigated screening tools [14].

According to Nardi et al 2018, certain conventional images are highly indicated in certain mandibular fractures; namely lateral oblique images for body and ramus fractures, posteroanterior images in cases of the ramus, angle, symphysis, and Para symphysis fractures and reverse Towne's view as being the best image to reveal the sub-condylar fracture [13].

Accordingly, these additional conventional views were also performed in the current study following these anatomic locations of mandibular fractures to preclude their exact role in such cases to avoid exposing the patients to extra unneeded radiation.

Naeem and Cawson stated that CBCT has recently been developed as an alternative to conventional CT for dental and maxillofacial diagnostic osseous tasks. CBCT allows imaging of the maxillofacial region with a shorter scanning time while the radiation dose is lower compared with conventional CT scans [15, 16].

CBCT dose varies substantially depending on the device, FOV (Field of view), and selected technique factors. Consequently, and following the previous recommendations, CBCT was chosen to provide the 3D images in the current work.

Consequently, this study was designed to determine and compare the accuracy and diagnostic reliability of the two imaging modalities (2D and 3D) in the assessment of mandibular fractures as an attempt to combine the usefulness and limitations of both techniques in the field of traumatology.

For each patient in the current work, the authors compared the sensitivity of conventional radiography and each of the investigated CBCT images to the known surgical findings. In this analysis, each radiologic examination was considered a true positive if all fractures present were correctly identified or a false negative if any fracture was missed. The sensitivity of each radiologic examination was calculated as the probability of correctly identifying fractures that were truly present. The specificity could not be estimated because the diagnosis of the true negative was not confirmed since surgical intervention occurred only for suspected fractures.

4.2. Discussion of Results

In our opinion, the less diagnostic efficacies of 2D panoramic radiographs in assessing mandibular fractures might be attributed to the inability of precise positioning of traumatized cases which is impaired by the patient's injury. Hence, Para symphyseal regions might have been obscured by the superimposition of underlying structures such as the vertebral column. Fractures in these areas are usually difficult to interpret by panoramic radiographs in the absence of dislocation. Angular fractures that were falsely visible on panoramic radiographs also implicate that superimposition of soft tissue density or glosso-pharyngeal air space might be interpreted as fractures on the panoramic radiographs giving false-positive results in this region. Furthermore, motion during the exposure of a panoramic view can produce a false image.

These results are following the work of Truong. He found that un-displaced condylar and sub condylar fractures might be overlooked in panoramic radiographs [17].

On the contrary, Roberts et al compared the identification of mandible fractures by helical computed tomography and panoramic imaging [18].

Murugaiah S et al stated that lateral oblique projections were inferior to CBCT images and even reversed Towne's views in the assessment of mandibular fractures due to the superimposition of the glossopharyngeal space because of improper patient positioning and improper aiming of the central ray to target the exact region of interest. Consequently, it resulted in the misdiagnosis of imaginary mandibular fractures [19].

The “Gold Standard” for the current work was the results of the surgical intervention as well as the clinical diagnosis. The specificity could not be estimated because the diagnosis of the true negative was not confirmed since surgical intervention occurred only for suspected fractures. Also, for the same reason, no accuracy measures were calculated for displacement, comminutions, and effect on teeth and the inferior alveolar canal (IAC).

Axial, cross-sectional, reformatted panoramic views, and 3D CBCT images revealed 100% sensitivity and 100% accuracy in demonstrating the presence and number of fracture lines in the present work. Meanwhile, panoramic images yielded 81.8% sensitivity and diagnostic accuracy respectively in detecting fractures, and 90.9% sensitivity and diagnostic accuracy respectively in detecting the number of fracture lines.

Using PA and lateral oblique as supplementary imaging aids in combination with 2D panoramic images did not greatly enhance the diagnostic capabilities in detecting fractures or revealing the number of fracture lines. Lateral oblique images recorded equivocal sensitivity and diagnostic accuracy values for detecting site and number of fractures; 33.3% and 33.3% for both tested findings. PA images didn’t accurately detect fracture, site of the fracture, and the number of fracture lines. So, their sensitivity and diagnostic accuracies were 0% and 0%, respectively. On the contrary, reverse Towne’s was highly sensitive and accurate (100% and 100% respectively) in detecting sub condylar fractures, localizing their site, and revealing the number of encountered fracture lines.

Moreover, Murugaiah S et al, Afrooz PN et al, Ersan N, White SC and Baykul T et al reported results that were in concordance with our findings and attributed his results to the fact that cross-sectional imaging together with the development of volume-acquisition of data has provided the superior capability of morphologically detailed 3D imaging and tracing of the fractures in any area in the mandible [19-23].

Nardi et al, Baykul and Legome reported that as compared with conventional radiographs, 3D images provided superior detection of the number of fracture lines in addition to a great definition of fracture lines (especially horizontal ones) and better appreciation of the extent of comminution than axial and cross-sectional images in the work done by [13, 23, 24].

But according to Egbert, CBCT had a geometric accuracy in revealing the displacement in all windows in the 3D, axial, coronal, and even in a reconstructed panoramic view like our results [25].

Kau et al stated that CBCT offers a great diagnostic tool which is the detection and location of anatomic structures such as the inferior alveolar nerve (which is easily traced and navigated using the CBCT inherent software), and mental foramen [26].

Afrooz et al, Ersan, White and Kau et al stated that the assessment of the relation between the fracture and teeth, there was no great difference between the CBCT images and the conventional panoramic views. This finding goes in alignment with the reports given by [20, 21, 22, 26].

Afrooz et al and Ersan stated that the areas of comminution were best revealed by the axial and reconstructed coronal cuts which showed high sensitivity while the reconstructed sagittal and reconstructed panoramic views showed a very low diagnostic accuracy regarding detection of comminution as proved in the work done by [20, 21].

Różyło-Kalinowska I stated that panoramic radiography creates only flat, two-dimensional, supero-inferior, or posteroanterior images and it suffers from the superimposition of all structures that lie in the path between the X-ray source and the film and the detector. Consequently, it might be less sensitive in assessing the location, extent, and displacement of fractures in many cases [1].

In the current work, one of the cases had one mandibular body fracture, the panoramic view revealed false positives for two lines of fractures. CBCT examination; axial, coronal, reconstructed panoramic view, and 3D images all revealed confirmed the presence of just one fracture line in agreement with the gold standard.

The study has confidence and supports that diagnostic accuracy taken by CBCT has a statistical difference from that taken by the conventional extra-oral techniques. The Scope of this study focused on the importance of using the three-dimensional radiographic technique in diagnosing and evaluating the mandibular fractures due to their numerous types and their many complications and the false-negative diagnosis that result when we rely only on the two-dimensional extra-oral technique. The use of CBCT as a lower radiographic dose from the CT and higher diagnostic capability than the two-dimensional extraoral techniques could be reliable, time-saving, applicable, reproducible, and of clinical significance for maxillofacial surgeons and even general practitioners in the dental field, as it is considered to be a reproducible study that can be repeated in any search in different ways and can be repeated in any clinical situation. The clinical recommendation of this study is the need for further, long-term clinical studies to confirm the current results.

5. Conclusion

The following conclusions can be drawn from this study:

1. Despite the evaluability of panoramic radiography in the evaluation of mandibular fracture, it should not be relied on as the sole measure for diagnosing fractures. CBCT should be used for their advantages to evaluate specific sites of the mandible when panoramic radiography is negative and clinically there is a reason to believe that a fracture does exist.
2. In cases of the symphysis, para-symphysis, angle, and latero-medial displaced sub condylar fractures, the panoramic view is not recommended. CBCT views are the techniques of choice for highlighting the nature of fracture by directly viewing the extent of the fracture, as well as the degree and direction of displacement if present.

3. Panoramic views and CBCT images are both capable of detecting and observing the involvement of teeth in the site of fracture.
4. Panoramic views could yield false-positive results in the detection of the number of fractures and the extension of the fracture in comparison to the highly sensitive CBCT imaging.
5. CBCT is a reliable means of determining the location of the IAC and its relationship to the sites of fractures and in this respect is more reliable than conventional radiography.
6. CBCT plays a major and significant role with high sensitivity in the observation of comminuted fragments which could be misdiagnosed on conventional images.
7. The application of computer systems and the development of electronic detection have provided the technical means to apply theoretical principles, such as digital acquisition, to diagnostic imaging in maxillofacial trauma.

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Conflicts of Interest

All the authors do not have any possible conflicts of interest.

Patient Declaration of Consent

Before performing any procedure, all patients received a thorough explanation concerning the clinical procedures as well as the possible risks and radiation hazards. Informed written consent was obtained from all the study participants. The performance of this study was approved by the research ethics committee of Cairo University. Moreover, certificates from the Ministry of Health (Center of Medical Research) were presented for permitting subjecting the patients to CBCT.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article (and/or) its supplementary materials by contacting to corresponding author mail.

Ethical Policy and Institutional Review Board Statement

Before performing any procedure, all patients received a thorough explanation concerning the clinical procedures as well as the possible risks and radiation hazards. Informed written consent was obtained from all the study participants. The performance of this study was approved by the research ethics committee of Cairo University. Moreover, certificates from the Ministry of Health (Center of Medical Research) were presented for permitting subjecting the patients to CBCT. The ethical clearance for this research was officially approved by the Ethical Clearance Committee by the Faculty of Dentistry, Cairo University with the registration number (15/6/38 date 24/06/2009).

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