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Author

de Carvalho, MF, Vieira, JNM, Figueiredo, R, Reher, P, Chrcanovic, BR, das Graças Afonso Miranda Chaves, M

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Validity of computed tomography in diagnosing midfacial fractures

Matheus Furtado de Carvalho[1], José Nélson Mendes Vieira[2], Reginaldo Figueiredo[2], Peter Reher[3], Bruno Ramos Chrcanovic[4], Maria das Graças Afonso Miranda Chaves[1]

[1] Federal University of Juiz de Fora, Juiz de Fora, Brazil

[2] Federal University of Minas Gerais, Belo Horizonte, Brazil

[3] School of Dentistry and Oral Health, Griffith University, Gold Coast, Australia

[4] Faculty of Odontology, Malmö University, Malmö, Sweden

Corresponding author

Matheus Furtado de Carvalho

Universidade Federal de Juiz de Fora

Rua José Lourenço Kelmer, s/n, São Pedro, Juiz de Fora, Brazil, CEP 36036-900

e-mail: dr.matheusfurtado@yahoo.com.br

Tel: +55 (32) 2102-3851

Keywords

Computed tomography; facial trauma; midfacial fractures; diagnosis

Statement of Originality

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ABSTRACT

The aim of the present study was to evaluate the sensitivity, accuracy and reliability of 2D-CT scans (axial, coronal, sagittal planes) and 3D-CT reconstructions in diagnosing midfacial fractures in relation to actual fractures identified clinically and during surgery (gold standard), performed by a radiologist and an oral and maxillofacial surgeon. Sixty-five patients with a total of 429 midfacial fractures were included. Frontal sinus and nose fractures were easily diagnosed. There was a statistically significant difference between the CT examination and the gold standard in 5-7 out of the 9 bones evaluated for the three CT planes, while for the 3D-CT a difference was observed only for fractures of the orbital floor. The inter-observer agreement between the OMFS and the radiologist was 75.5%. In conclusion, this study shows that 3D-CT reconstructions showed significantly the best sensitivity, accuracy and reliability for the diagnosis of midfacial fractures. Of the 2D-CT images, the least diagnostic were the sagittal reconstructions. For areas where the studied parameters showed less agreement and hence a more difficult diagnosis, we recommend a combination of 3D and 2D-CT images to improve diagnostic accuracy.

INTRODUCTION

For many decades, the diagnosis of midfacial fractures was routinely based on clinical examination complemented by extra-oral radiographic examinations. The establishment of a diagnosis was sometimes a challenge for oral and maxillofacial surgeons (OMFS), due to a low contrast level between facial tissues and a high rate of overlap in bone structures[1]. Advances in science contributed to better imaging devices, which resulted in a more accurate evaluation of the facial fractures, particularly fractures in the middle skeleton of the face. Computed tomography (CT) had an important role in this context, by providing a greater definition of fractures lines, localization, extension, degree of dislocation, and rotation of bone segments[2]. By providing a more accurate diagnosis, CT and cone beam CT (CBCT) have significantly changed the decision making process in oral & maxillofacial surgery, making surgical procedures faster and safer[3].

However, the widespread use of the technology has also lead to an excessive reliance on its results by clinicians, minimizing unfortunately the importance of thorough clinical examinations. The massive use of CT images for all types of facial fractures has generated an overload in radiology centers and higher costs for CT device maintenance[4].

It is, therefore, necessary to better understand the recommendations for CT concerning the benefits of diagnosis, treatment planning and evaluation, without causing even greater expenses for hospitals, professionals, and patients. The aim of the present study was to evaluate the sensitivity, accuracy and reliability of 2D-CT scans and 3D-CT reconstructions in diagnosing midfacial fractures.

MATERIALS AND METHODS

Inclusion and exclusion criteria

This prospective clinical cohort study was carried out at the João XXIII Hospital, in the city of Belo Horizonte, Brazil. All patients with facial trauma suspected of presenting midfacial fractures and referred to the aforementioned hospital for a period of 12 months were eligible for the study. Each patient needed to have undergone a preoperative CT examination of the midface. Exclusion criteria were patients who did not provide their consent to be included in the study, patients that had previous facial fractures and patients that did not require a surgical intervention to manage their fractures. The study protocol was approved by the ethical committee of the hospital network (Fundação Hospitalar de Minas Gerais, Register CEP/FHEMIG 110/2009). The study was conducted in accordance with the Helsinki declaration, and followed the STROBE guidelines.

Study phases

The study was divided into three phases: 1) clinical data collection, by one OMFS; 2) CT images evaluation, independently by one OMFS and one radiologist; and 3) transoperative surgical data collection, by a second OMFS who operated all patients.

CT scans

The tomographic examinations were performed using a Siemens 64-channel Multislice Somatom Sensation scanner (Siemens AG, Munich, Germany). The scans were obtained and configured by a radiology technician, according to the following protocol: 1.0 mm thick slices with 0.5 mm interval for reconstruction, 120 kVp, 150 mA, matrix 512 x 512, using bone kernel.

The data for each patient was transmitted to a workstation in traditional DICOM (Digital Imaging Communications in Medicine) format and the reconstructed images were visualised with the software Siemens Syngo fastView (Siemens AG, Munich, Germany). Standard 2-dimensional (2D-CT) sets were generated in axial, coronal and sagittal planes (Figures 1A-C). In addition, 3-dimensional reconstructions (3D-CT) were obtained in frontal view, frontal-nasal angulation view, mento-nasal angulation view, Hirtz view, bilateral profile views, and bilateral 45^{o} profile views (Figure 1D).

Imaging Analysis

All professionals that analyzed the images were previously calibrated, namely the two examiners were trained systematically and calibrated with each other regarding the presence or absence of midfacial fractures. The evaluation of the images was again performed at a second moment 30 days after the first analysis, by the same OMFS (7 years of experience in reading CT) and radiologist (10+ years of experience). The “gold standard” diagnosis of midfacial fractures was established transoperatively, by a second OMFS not involved in the CT images evaluation.

A simple midfacial fractures classification system was used as previously described [5], grouping the fractures into frontal sinus fractures; orbital fractures (floor, roof, lateral and medial wall); nasal fractures; zygomatic arch fractures; maxillary sinus fractures; and palate fractures.

Statistical analysis

A descriptive analysis was performed based on mean, standard deviation (SD), and percentage values. The 30-day intra-observer agreement and the inter-observer agreement between the OMFS and the radiologist were calculated.

The sensitivity, specificity, accuracy, and the predictive positive and negative values for the CT images diagnosis in relation to the gold standard were calculated. *Sensitivity* was defined as the proportion of identified fractures by the CT images evaluation that correlated to actual fractures identified clinically and during surgery ("gold standard"), in other words, true positive results. *Specificity* was defined as the proportion of the absence of midfacial fractures that were identified as such by the CT images evaluation (true negative results). *Positive* and *negative predictive values* (PPV and NPV, respectively) were defined as the proportions of positive and negative results that were true positive and true negative results, respectively. *Accuracy* was defined as the proportion of correct predictions (both true positives and true negatives) among the total number of cases examined.

The Kappa test was performed in order to evaluate the reliability of the CT images diagnosis compared to the gold standard, for each group of fractures. The Kappa coefficients results were grouped into excellent agreement (1.0 to 0.81), substantial (0.8 to 0.61), moderate (0.6 to 0.41), fair (0.4 to 0.21) and poor (below 0.2).

The significance of the difference to correctly diagnose midfacial fractures between CT scans and the clinical-surgical diagnosis was calculated by the McNemar's chi-squared test, for each of the nine simple midfacial fractures and each scan plane and reconstruction (2D axial, 2D coronal, 2D sagittal, and 3D reconstruction).

RESULTS

Sixty-five patients were initially assessed for this study. Three of these patients were excluded from the sample: two presented a bilateral mandibular condyle fracture without midfacial fractures, and one patient reported a history of midfacial fracture in the past. Of the 62 patients included in the study, 55 were male (88.7%) and 7 female (11.3%), with a mean age of 39 years (range 15-84).

A total of 429 midfacial fractures were identified: 77 maxillary sinus (17.9%), 71 orbital floor (16.5%), 53 orbital lateral wall, 46 nasal, 43 frontal, 36 orbital medial wall, 36 orbital roof, 34 palatal and 33 of zygomatic arch. The etiology of the midfacial trauma for the included patients was: motor vehicle accidents in 31 cases, falls in 14, violence (interpersonal aggression) in 7, violence with blunt or sharp objects in 4 cases, violence (gunshot) in 3, two work accidents, and one trauma accident while practicing sports.

The 30-day intra-observer agreement was 95% and 97% for the OMFS and the radiologist, respectively. The inter-observer agreement between the OMFS and the radiologist was 75.5%. There was a similar mean accuracy between radiologists (74.3%) and OMFS (76.4%) who diagnosed midfacial fractures from axial slices. By contrast, some difference in the 3D-CT reconstructions could be observed, as radiologists presented a mean accuracy of 80.6%, whereas OMFS presented a mean accuracy of 92.3%. The results of sensitivity, specificity, accuracy, positive and negative predictive values are shown in Table 1. In general, 3D-CT presented the best values for all these parameters in comparison to the 2D-CT images. Some results are worth commenting. The three CT planes (axial, sagittal, coronal) presented a relative low sensitivity for fractures of the orbit (medial wall and floor), zygomatic arch and palate. Accuracy results show again that 3D-CT's were better than 2D-CT's, with the worst result being for the 2D sagittal cut of the orbit floor.

The Kappa's reliability results are perhaps the best ones to identify which diagnosis image is more reliable, and which type of fracture is easier to be diagnosed (Table 2). In terms of fracture site, the frontal sinus, orbital roof and nose are the ones which are easier to diagnose. The 3D-CT images were the most reliable exams, and the 2D-sagittal the least reliable. It is worth noting that 2D sagittal images for the orbit (floor and medial wall), the palate; and the 2D coronal images of the zygomatic arch did show very poor agreement.

Table 3 shows the results concerning the statistical significance of the difference of computer tomography scans to correctly diagnosed midfacial fractures in relation to the clinical-surgical examination. The results are similar to the ones noted with the reliability results, confirming that frontal sinus and nose fractures are easily diagnosed. There was a statistically significant difference between the CT examination and the gold standard in 5-7 out of the 9 bones evaluated for the three CT planes, while for the 3D-CT a difference was observed only for fractures of the orbital floor.

DISCUSSION

Facial fractures can be disabling injuries that may require complex surgical care from oral and maxillofacial surgeons (OMFS). While sophisticated diagnostics and surgical treatment approaches have been developed and are routinely utilised in high resource healthcare systems, occult facial fractures are frequent, especially with low energy mechanisms, and may be missed on initial trauma surveys across the wide array of possible causes of trauma[6-8].

Although the incidence of facial fractures can be high, this varies greatly in different countries[9-14]. Worldwide facial fractures are predominantly driven by falls except in regions suffering from conflict[6]. Our study shows that most midfacial fractures were associated with motor vehicle accidents and violence, which unfortunately reflects common mechanisms of injury observed in Brazil.

Although this was not an epidemiological study, we identified that the maxillary sinus and the orbital floor were the most common fractures sites. The description of fractures used here is also different than the traditionally used such as zygomatic complex fractures, Le Fort fractures or naso-orbito-etmoidal (NOE) fractures. This traditional system often leads to duplication of results, for example, zygomatic fractures may be associated to Le Fort III fractures[15]. The classification system for fractures used in the present study follows classic anatomy based on fractured bone structures in an attempt to avoid double diagnosis[5].

Diagnosis of midfacial fractures can be challenging and require a thorough clinical examination by an experienced clinician and the use of good imaging exams. To ensure the tomographic evaluation is accurate, the image acquisition requires CT slices of no more than 1 mm in thickness[16]. The use of 3D reconstruction images has enhanced diagnostic abilities in mid-facial fractures, however, combining 3D-CT and 2D-CT analysis has been recommended, particularly in NOE fractures[17].

Midfacial fractures may be associated with the skull and cervical spine fractures. For this reason, the communication between trauma surgeons, neurosurgeons, and OMFS should be clear before recommending CT scans, to avoid repetition of exams and delays in the management of patients with severe trauma[18-20]. Standard head CT scans alone failed to identify a significant number of facial fractures compared with facial CTs in 35% of patients[21]. Facial CT scans should be considered for patients with known or suspected facial fractures, even if a head scan has been performed previously[21].

Our results show that 3D-CT reconstructions are more sensitive, accurate, reliable and significant, when compared to the gold standard. This is in agreement with previous studies that recommended the use of 3D-CT for all comminuted midfacial fractures[15,22]. One needs to point out that small non-displaced fracture of papyraceous bone, like the ethmoid bone and the inferior orbital wall, likely do not require surgery. Moreover, other studies showed that 2D-CT has better accuracy in diagnosing floor and medial orbital wall fractures compared with 3D-CT, because these are volume averaged on 3D-CT[23,24]. Thus, for some areas of difficult diagnosis such as the floor and medial wall of the orbit, we recommend a combination of 3D and 2D CT images to improve diagnosis, as also suggested by other authors[17,25].

Previous studies of orbital fractures imaging diagnosis showed that the association of 2D-Axial images and 3D-CT reconstructions has a sensitivity of 90.5%. This is reduced to 86.1% when associating 2D-Coronal images and 3D-CT[26]. These authors did not describe the 2D-Sagittal plane. In the present study, all orbital fractures also proved to be better identified in 3D-CT reconstructions, followed by 2D-Axial and 2D-Coronal, with the 2D-Sagital images showing the least sensitivity and accuracy. However, 3D-CT reconstructions have limitations when it comes to assessment of soft-tissue injury, which is often associated with facial fractures, as for example orbital fat herniation. These can only be assessed on 2D-CT with standard kernel.

We identified a statistically significant difference between the CT examination and the gold standard in 10 out of 12 orbital fractures for the three 2D-CT planes, while for the 3D-CT a difference was observed only for fractures of the orbital floor, suggesting these are more accurate. However in some cases, the use of 3D and 2D CT images will still need to be complimented during surgery with a sinus endoscopy to confirm orbital floor fractures[27].

The use of 2D-Axial slices is usually preferred by radiologists, while 3D-CT reconstructions are most popular with OMFS[25]. In the present study, it was possible to note a similar mean accuracy between radiologists (74.3%) and OMFS (76.4%) who diagnosed midfacial fractures from axial slices. By contrast, some difference in the 3D-CT reconstructions could be observed, as radiologists presented a mean accuracy of 80.6%, whereas OMFS presented a mean accuracy of 92.3%. These results demonstrate the importance of exchanging information between the teams, in order to obtain the best images and surgical planning.

The use of cone beam computer tomography (CBCT) is quite popular in many dental clinics and some hospitals nowadays. They are more cost-effective, have a very good diagnostic value, and allow reconstruction of oblique images extracted from the 3D data, which is useful when assessing pure orbital floor fractures[28]. However, the main disadvantage of CBCT for midfacial fractures is that the patient needs to stand upright, which might be a problem for patients with severe head injuries, with cervical fractures or unconscious/sedated, and therefore they are not used routinely in most hospitals. Our study only evaluated 2D-CT and 3D-CT images from a multislice CT, as this is the CT machine of choice in large trauma centers.

Our results show that 2D-CT (axial, sagittal, coronal) could be used to diagnose frontal and nasal fractures safely. However, overall the best results for the diagnosis of midfacial fractures when comparing the image diagnosis with the gold standard was with 3D-CT reconstructions. It is important to emphasize that 3D-CT reconstructions are not 100% accurate for all fractures, particularly for the orbital floor. These false-positive results are mainly due to the incorrect interpretations of anatomic structures, such as fissures, foramina, and canals[29].

As a limitation of the present study, the inclusion of patients for this study was limited to patients who underwent surgery, which was considered the gold standard. It is reasonable to expect these patients to have more displaced and comminuted fractures than patients who did not undergo surgery.

In conclusion, this study shows that 3D-CT reconstructions showed significantly the best sensitivity, accuracy and reliability for the diagnosis of midfacial fractures, taking into consideration the aforementioned limitation. Of the 2D-CT images, the least diagnostic were the sagittal reconstructions. For areas where the studied parameters showed less agreement and hence a more difficult diagnosis, we recommend a combination of 3D and 2D-CT images to improve diagnostic accuracy. Finally, one should never underestimate the significance of a thorough clinical assessment of our patients and not rely exclusively in good imaging diagnosis when managing complex facial trauma cases.

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CAPTION OF ILLUSTRATIONS

Figure 1 – Example of CT images analyzed in this study: (A) 2D axial cuts, (B) 2D sagittal cuts, (C) 2D coronal cuts, and (D) 3D reconstruction (frontal view). Red arrows show sites of fracture.

Table 1. The results of sensitivity, specificity, accuracy, positive and negative predictive values for the comparison of the diagnosis of midfacial bone fractures between the CT imaging analysis and the Gold Standard (clinical-surgical examination).

Bone/Region	CT Image	Sensitivity	Specificity	Accuracy	PPV	NPV
Frontal sinus	2D-Axial	1.000	0.974	0.985	0.963	1.000
	2D-Sagittal	0.923	0.974	0.954	0.960	0.950
	2D-Coronal	0.962	0.974	0.969	0.962	0.974
	3D-CT	1.000	1.000	1.000	1.000	1.000
Orbit (roof)	2D-Axial	0.677	1.000	0.846	1.000	0.773
	2D-Sagittal	0.484	0.971	0.738	0.938	0.673
	2D-Coronal	0.742	1.000	0.877	1.000	0.810
	3D-CT	0.903	1.000	0.954	1.000	0.919
Orbit (lateral wall)	2D-Axial	0.773	0.810	0.785	0.895	0.630
	2D-Sagittal	0.523	1.000	0.677	1.000	0.500
	2D-Coronal	0.705	0.905	0.769	0.939	0.594
	3D-CT	0.955	1.000	0.969	1.000	0.913
Orbit (medial wall)	2D-Axial	0.296	1.000	0.708	1.000	0.667
	2D-Sagittal	0.148	1.000	0.646	1.000	0.623
	2D-Coronal	0.593	1.000	0.831	1.000	0.776
	3D-CT	0.778	0.974	0.892	0.955	0.860
Orbit (floor)	2D-Axial	0.510	0.929	0.600	0.963	0.342
	2D-Sagittal	0.471	0.857	0.554	0.923	0.308
	2D-Coronal	0.686	0.786	0.708	0.921	0.407
	3D-CT	0.824	0.929	0.846	0.977	0.591
Nasal	2D-Axial	0.645	0.853	0.754	0.800	0.725
	2D-Sagittal	0.742	0.853	0.800	0.821	0.784
	2D-Coronal	0.806	0.912	0.862	0.893	0.838
	3D-CT	0.903	0.941	0.923	0.933	0.914
Zygomatic arch	2D-Axial	0.600	0.886	0.754	0.818	0.721
	2D-Sagittal	0.300	1.000	0.677	1.000	0.625
	2D-Coronal	0.233	0.943	0.615	0.778	0.589
	3D-CT	0.967	1.000	0.985	1.000	0.972
Maxillary sinus	2D-Axial	0.745	0.900	0.769	0.976	0.391
	2D-Sagittal	0.655	1.000	0.708	1.000	0.345
	2D-Coronal	0.727	1.000	0.769	1.000	0.400
	3D-CT	0.909	0.900	0.908	0.980	0.643
Palate	2D-Axial	0.433	0.886	0.677	0.765	0.646
	2D-Sagittal	0.200	0.971	0.615	0.857	0.586
	2D-Coronal	0.433	0.971	0.723	0.929	0.667
	3D-CT	0.800	0.857	0.831	0.828	0.833

PPV - positive predictive value, NPV - negative predictive value

Table 2. Agreement of diagnosis between the CT imaging analysis and the Gold Standard (Cohen's Kappa).

Bone/Region	**Gold standard vs. CT Analysis**			
	2D-Axial	2D-Sagittal	2D-Coronal	3D-CT
Frontal sinus	0.97	0.90	0.94	1.00
Orbital roof	0.69	0.46	0.75	0.91
Orbital lateral wall	0.54	0.43	0.55	0.93
Orbital medial wall	0.33	0.16	0.63	0.77
Orbital floor	0.27	0.20	0.35	0.62
Nose	0.50	0.60	0.72	0.84
Zygomatic arch	0.49	0.32	0.19	0.96
Maxillary sinus	0.42	0.36	0.45	0.74
Palate	0.32	0.19	0.44	0.66

Legend:	Kappa 0.01-0.20	Poor agreement
	Kappa 0.21-0.40	Fair agreement
	Kappa 0.41-0.60	Moderate agreement
	Kappa 0.61-0.80	Substantial agreement
	Kappa 0.81-1.00	Excellent agreement

Table 3. Significance of the difference of computer tomography scans to correctly diagnose midfacial fractures in relation to the gold standard (McNemar's chi-square test).

Bone	Gold standard vs.			
	Axial	Sagittal	Coronal	3D-CT
Frontal sinus	1.000	1.000	1.000	1.000
Orbital roof	0.002*	<0.001**	0.008*	1.000
Orbital lateral wall	0.180	<0.001**	1.000	0.500
Orbital medial wall	<0.001**	<0.001**	0.001*	0.125
Orbital floor	<0.001**	<0.001**	0.004*	0.021*
Nose	0.210	0.581	0.508	1.000
Zygomatic arch	0.077*	<0.001**	<0.001**	1.000
Maxillary sinus	0.001*	<0.001**	<0.001**	0.219
Palate	0.007*	<0.001**	<0.001**	1.000

* Significant

** Highly significant