Radiography xxx (2016) 1–5

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Substantial CT radiation dose reduction does not affect the preference for CT over direct digital radiography to diagnose isolated zygomatic fractures – A study in human cadavers

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A R T I C L E I N F O

Article history:
Received 16 March 2016
Received in revised form
11 July 2016
Accepted 31 July 2016
Available online xxx

Keywords:
Zygomatic fractures
Diagnostic imaging
Radiography
X-ray computed tomography
Radiation dosage

A B S T R A C T

Introduction: Zygomatic fractures can be diagnosed with either computed tomography (CT) or direct digital radiography (DR). The aim of the present study was to assess the effect of CT dose reduction on the preference for facial CT versus DR for accurate diagnosis of isolated zygomatic fractures.
Materials and methods: Eight zygomatic fractures were inflicted on four human cadavers with a free fall impactor technique. The cadavers were scanned using eight CT protocols, which were identical except for a systematic decrease in radiation dose per protocol, and one DR protocol. Single axial CT images were displayed alongside a DR image of the same fracture creating a total of 64 dual images for comparison. A total of 54 observers, including radiologists, radiographers and oral and maxillofacial surgeons, made a forced choice for either CT or DR.
Results: Forty out of 54 observers (74%) preferred CT over DR (all with $P < 0.05$). Preference for CT was maintained even when radiation dose reduced from 147.4 μSv to 46.4 μSv (DR dose was 6.9 μSv). Only a single out of all raters preferred DR ($P = 0.0003$). The remaining 13 observers had no significant preference.
Conclusion: This study demonstrates that preference for axial CT over DR is not affected by substantial (~70%) CT dose reduction for the assessment of zygomatico-orbital fractures.

Introduction

The orbito-zygomatic area represents the major fracture site among maxillofacial traumas.[1–4] Traffic accidents and assault have been described as the main causes of zygomatic fractures.[1,4–6] It has been demonstrated that early and correct diagnosis are important factors determining treatment outcome.[7–9] Both clinical examination and diagnostic imaging are used for the assessment of potential zygomatic fractures. Isolated zygomatic fractures are suspected after midface trauma with low clinical index of suspicion for orbital or visual complications. Computed tomography (CT), direct digital radiography (DR) and Cone Beam Computed Tomography (CBCT) are the current imaging modalities to assess zygomatic fractures.[9–11] This study focuses on the use of CT and DR due the current lack of CBCT accessibility in the emergency department.

In many cases, DR is first choice to check bone integrity after facial trauma. It is quick, easy accessible in most hospitals and associated with low radiation dose.[11] Apart from these benefits, DR has a few imperative disadvantages. First, the positioning of the head can be difficult causing discomfort to the patient. Second, the images are relatively difficult to interpret due to superimposition of bone structures. Finally, if the assessment is inconclusive, patients need to undergo an additional CT scan, thereby adding to radiation burden. Nowadays, in most emergency room (ER) settings CT is

Abbreviations: CBCT, cone beam computed tomography; DR, direct digital radiography; CT, computed tomography; MPR, multiplanar reconstructions; OMF, oral and maxillofacial.

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http://dx.doi.org/10.1016/j.radi.2016.07.007
1078-8174/

very easily accessible. Compared to DR, multidetector CT requires considerable less time, is safer, and more comfortable for patients.[12–15] The question however remains whether or not the high radiation dose is justified in cases of non-complex maxillofacial trauma, like zygomatic fractures. The use of low dose CT might combine the advantages of CT and DR, but it is unclear to what extend low dose CT images are preferred compared to DR for diagnosing zygomatic fractures. The aim of the present study therefore was to assess the effect of CT dose reduction on the preference of radiographers, radiologists and oral and maxillofacial (OMF) surgeons for facial CT versus DR for accurate diagnosis of isolated zygomatic fractures.

Material and methods

Research design

Zygomatic fractures were inflicted on four human cadaver heads. Subsequently, both CT and DR images were generated. Multi spiral CT scans were performed with linear dose reduction as achieved by raising the noise index for eight different CT protocols. Evaluation of the images was performed by a panel of 54 independent observers, consisting of 37 radiographers, 13 radiologists and 4 OMF surgeons. Selection criterion for participating in the observer group was to have clinical experience in generating and technically evaluating both CT and DR images for their diagnostic value in clinical practice for at least one year. Observers compared CT images with DR images in random order during a double blind forced choice comparison test, *i.e.* both the researchers and observers were blinded for the scan parameters that were used to generate the presented CT image.

Human cadaver heads

Four fresh Caucasian adult human cadavers (two males and two females) were used in this study. Their age ranged from 72 to 87 yr. The human cadavers were purchased from and provided by the section anatomy of the Department of Neurosciences of the University Medical Center Groningen, Groningen, the Netherlands. Legal and ethical approval for the use of the human cadavers was provided by the section anatomy of the Department of Neurosciences of the University Medical Center Groningen, Groningen, the Netherlands. All experiments were conducted in collaboration with the conservators of the Anatomy Section and were executed according to standards for working with human cadavers as provided by Dutch law.

Infliction of zygomatic fractures

A blunt trauma was systematically inflicted using 2.0 kg weights and a free fall impact in attempt to inflict zygoma-orbital fractures typically found in clinical practice. During a vertical drop, a 160 cm tube guided the weights to the malar eminence (Fig. 1). A calculation based on the biomechanical tolerance force of the zygomatic bone indicated a minimal drop height of 72 cm.[16] The human cadaver heads were placed on a 52° wooden wedge to ensure perpendicular impact on the malar eminence (Fig. 2). An OMF surgeon clinically examined the midface of the specimen after impact, focusing on flattening of the cheek and steps at the infraorbital rim or at the location of the zygomatic alveolar crest in order to confirm the zygoma-orbital fractures. Fractures were inflicted on both the left and the right zygoma within each cadaver head.

Figure 1. Infliction of the zygomatic fractures. The zygoma-orbital fractures were systematically inflicted on the cadaver head using 2 kg weights and a free fall impact. A 160 cm tube guided the weights to the malar eminence during a vertical drop.

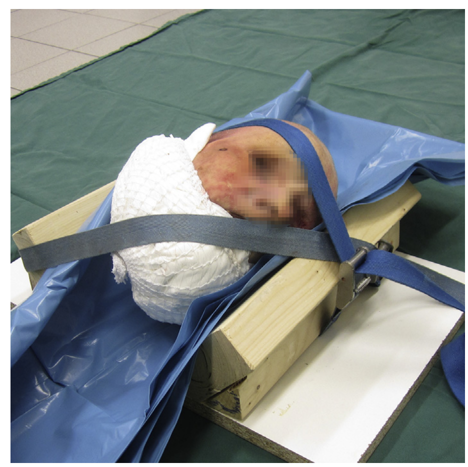

Figure 2. Placement of the human cadaver heads for the infliction of the zygomatic fractures. The cadaver heads were placed on a 52° wooden wedge to ensure perpendicular impact on the malar eminence. In the picture, the face was pixelized for ethical reasons.

Computed tomography

The zygomatic-orbital fractures were scanned using a GE Lightspeed Ultra 8 Slice CT (General Electric Co., Fairfield, Connecticut, United States). Facial multidetector CT was performed using the acquisition parameters as reported in Table 1. Linear dose reduction was achieved by raising the noise index for eight different CT protocols (Table 1). The effective dose was calculated using dose length products (DLP) and conversion factors according to the European guidelines on quality criteria for computed tomography.[17]

Direct digital radiography

DR images were generated using a calibrated Oldelft Canon Triathlon DR (Oldelft Benelux Ltd., Veenendaal, The Netherlands). Details regarding the acquisition parameters were provided in Table 2. For each specimen four different DR images were taken. The cadaver heads were positioned on a bed for occipitomental projection. From this position DR images were generated 15° craniocaudal, perpendicular vertical (Waters), 15 and 30° caudocranial

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Table 1
General Electric Lightspeed Ultra 8 Slice Computed Tomography scanner acquisition parameters for the eight different scan protocols.

Scan type	Helical
Tube voltage	100 kV
Noise index range	24.00–60.00
Slice thickness	0.625 mm
Position increment	0.625 mm
Collimation	8 × 0.625 mm
Average scan range	109 mm
Pitch	1.0
Rotation time	1.0 s
Exposure time	1.3 s
Grayscale depth	16 bit
Field of View (FOV)	250.0 mm
Matrix	512 × 512
Reconstruction type	Filtered Back Projection
Convolution kernel	BonePlus

Table 2
Oldelft Canon Triathlon DR acquisition parameters.

Tube voltage	70 kV
Exposure control mode	AEC
Focal Distance	100 cm
Filtration	0.1 mm Cu
Grayscale depth	12 bit
Grid ratio	8:1 (focussed)
Detector type	Scintillation Flat panel
Pixels	2208 * 2688 pixels
Pixel pitch	160 * 160 microns
Spatial resolution	160 micron

to ensure a full view of the midface anatomy. Effective dose normalization to dose area products (mSv/Gy·cm^2) was derived from report NRPB-R262 of the British National Radiological Protection Board (IRCP-60).[18]

Image assessment

For forced comparison, a representative DR image as well as a single and representative CT image from each of the eight different dose protocol scans was selected by an experienced and independent radiologist, who was subsequently excluded from the image assessment for this research study. The single slice that was chosen was at the same level of anatomy for each scan protocol. For each human cadaver head the eight different CT images were randomly paired with the corresponding DR image. A heterogeneous group of observers consisting of 37 radiographers, 13 radiologists and 4 OMF surgeons from the University Medical Center Groningen (Groningen, NL), Deventer hospital (Deventer, NL), and the Nij Smellinghe hospital (Drachten, NL) rated each of the 64 comparisons (specimen (1–4), side (left/right), and CT protocol (1–8). Each observer was forced to select a preferred image from a randomly paired comparison of a CT- and DR image of the same fracture (Fig. 3). The observer was asked to select the image in which the fracture was better visualized, so either DR or CT. Images were evaluated on a dual 3 MP Eizo Radiforce GS310 or dual 5 MP Eizo Radiforce G51 monochrome AAPM validated monitor (Eizo Nanao Co., Hakusan, Japan).

Statistical analysis

The null hypothesis of 0.50 CT preference was tested against its two-sided alternative by the proportions test.[19,20] The proportion of preference for CT was computed separately per profession, side, specimen and CT dose together with its 95 percent confidence interval. Finally, a generalized estimation approach was used to model the preference responses by generalized mixed models (repeated logistic regression) using observers as random effects in order to test for possible effects of side, profession, specimen and CT dose.[21,22] With respect to the latter, the degree of noise was centered and added as a co-variate to the model. P-values <0.05 were considered statistically significant.

Results

All 54 observers completed the forced choice comparison test. A total number of 40 out of 54 observers had a significant preference for CT over DR. Only a single observer (a radiologist) had a significant preference for DR. The remaining 13 observers had no significant preference. An overview of all preferences is shown in Table 3.

The proportion of preference for CT was computed separately per profession, side, specimen and CT dose (Table 2). Under all experimental conditions there is a significant preference for CT (proportion > 0.5 and all 95% confidence intervals are to the right hand side of 0.5). The preference for CT sustained after substantial (~70%) dose reduction from 147,4 μSv to 46,4 μSv (Tables 4 and 5). DR dose was 6,9 μSv (Table 5).

In order to correct for inter-dependencies within observers a repeated logistic regression was performed (Table 6).[21,22]

The resulting difference in log odds between right and left sides of the cadaver head is not significant ($p = 0.67$). This indicates that there was no difference in preference for either CT or DR within the cadaver heads, though there were difference between the four cadaver heads. For this reason the preferences were not analyzed statistically for each individual fracture. Instead, fractures within one human cadaver head were analyzed, resulting in an $N = 4$ sample size instead of $N = 8$. There was a difference in log odds between human cadaver head 2 and 4 compared to human cadaver head 1. Reduction of CT radiation dose by ~70% did not influence the preference for CT; observers consistently preferred CT for fracture detection even after lowering radiation dose. After correcting for profession, side, specimen and CT dose, the estimated odds of the CT preference of OMF surgeons is $\exp(0.77) = 2.16$ times that of a radiographer, which is in line with the ratio of odds $0.89/(1-0.89)/(0.77/(1-0.77)) = 2.42$ obtained from the proportions in Table 5. The difference in log odds between radiographers and radiologists is not significant, whereas that between radiographers and OMF surgeons is (Table 6).

Discussion

The increased radiation dose of CT as compared to DR is a significant consideration weighing the risks versus benefits of CT as a primary diagnostic tool for the assessment of isolated zygomatic fractures. To our knowledge, the current study is the first to describe a significant preference for CT over DR, even after substantial (~70%) CT radiation dose reduction. These results support the applicability of low dose CT as a primary diagnostic tool for the assessment of isolated zygomatic fractures. The lowest CT dose was higher than that of DR (46,4 μSv versus 6.9 μSv respectively), but both are substantially lower than the baseline CT dose (147,4 uSv).

Three aspects of this study design will be discussed. The number of observers and the skew distribution of professions may be seen as a limitation of this study. However, the generalizability of the study was enhanced by double blindness of the design and conducting the experiment in three different hospitals in the Netherlands. The group of observers was heterogeneous as it represented the professions involved in the assessment of zygoma images, i.e. radiographers (37), radiologists (13) and OMF surgeons (4). Although the group of OMF surgeons was small in number, it

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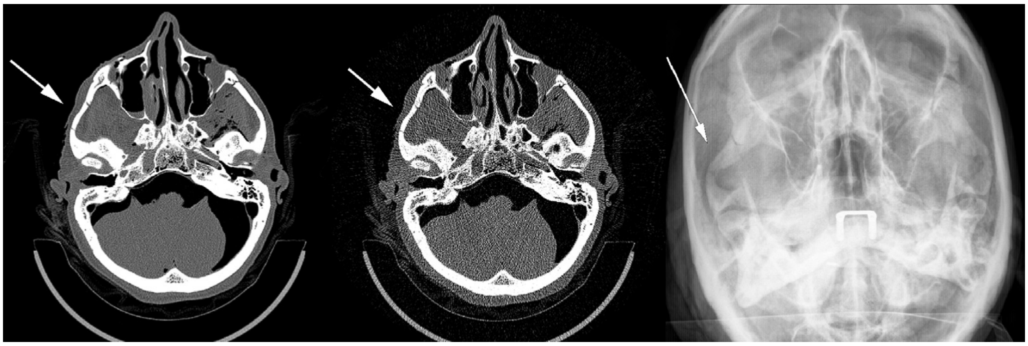

Figure 3. Randomly paired comparison of a CT- and DR image of the same fracture. Representative examples of CT, minimal dose CT and DR images of a zygomatic fracture (arrows). The rater was forced to select either the CT or the DR image of the same fracture in which the fracture was better visualized.

Table 3
Significant vs non-significant modality preference per profession.

	Radiographers	OMF surgeons	Radiologists	Total
Significant CT preference	29	4	7	40
Non-Significant CT preference	6	0	4	10
Significant DR preference	0	0	1	1
Non-Significant DR preference	2	0	1	3
Total	37	4	13	54

Direct digital radiography (DR), computed tomography (CT), oral and maxillofacial (OMF). P values < 0.05 were considered significant.

Table 4
Radiation dose results for each of the eight Computed Tomography scan protocols on average for the four human cadaver specimen.

Protocol	Noise index	Exposure (mA)	Tube current (mAs)	Scan range (mm)	$CTDI_{vol}$ (mGy)	DLP (mGy*cm)	Eff. Dose (μSv)
1	24.00	27.3 ± 8.3	14.3 ± 4.3	109	5.52	64.09	147.4
2	25.55	14.3 ± 4.3	13.3 ± 4.3	109	4.85	56.27	129.4
3	27.40	22.5 ± 8.0	12.0 ± 4.4	109	4.20	48.73	112.1
4	29.73	19.0 ± 6.9	10.0 ± 3.2	109	3.56	41.33	95.0
5	32.81	15.0 ± 5.3	8.3 ± 2.5	109	2.92	33.84	77.8
6	37.00	11.0 ± 2.9	6.0 ± 1.9	109	2.36	27.61	63.5
7	43.50	9.0 ± 0	4.3 ± 0.4	109	1.91	22.16	51.0
8	60.00	5.3 ± 2.2	3.3 ± 0.4	109	1.74	20.19	46.4

Computed Tomography Dose Index Volume (mGy) ($CTDI_{vol}$), Dose Length Product (mGy*cm) (DLP), Effective dose (μSv) (Eff. dose).

Table 5
Proportion of CT preference with left and right limit of 95 percent confidence interval for profession, specimen, side and CT dose. DR dose was 6.9 μSv.

	Proportion	95% CI
Profession		
Radiographers	0.77	0.75–0.79
Radiologists	0.67	0.64–0.70
OMF surgeons	0.89	0.84–0.92
Specimen		
1	0.74	0.71–0.77
2	0.84	0.81–0.86
3	0.77	0.74–0.80
4	0.68	0.65–0.71
Side		
Left	0.78	0.76–0.80
Right	0.73	0.71–0.75
Effective CT Dose (μSv)		
147.4	0.76	0.72–0.80
129.4	0.76	0.71–0.80
112.1	0.77	0.73–0.81
95.1	0.79	0.75–0.83
77.8	0.75	0.71–0.79
63.5	0.75	0.71–0.79
51.0	0.73	0.69–0.77
46.4	0.73	0.68–0.77

Direct digital radiography radiography (DR), computed tomography (CT), oral and maxillofacial (OMF).

demonstrated a homogeneous preference for CT. Our results are consistent in the a vast majority of the observers preferred CT to DR, with a single clear exception.

Second, a certain degree of ‘observer weariness’ may have occurred after evaluating 64 image combinations. However, due to the random design of the forced choice comparison it seems safe to exclude such an effect.

The third aspect is the fact that for this research a single axial CT slide only was used as opposed to the clinical practice where multiplanar reconstructions (MPR) are being used. MPR increase the effectiveness of visualization of fractures, especially in inferior

Table 6
Estimated effects of profession, side, specimen corrected for the noise index of CT by repeated binary (logistic) regression based upon fitting generalized estimating equations.

	EE	SE	Wald	p-value
Intercept	1.19	0.21	32.07	0.00
Radiologist	−0.41	0.31	1.72	0.19
OMF surgeon	0.77	0.20	14.66	0.00
Right side	0.07	0.17	0.18	0.67
Specimen 2	1.13	0.37	9.55	0.00
Specimen 3	−0.36	0.24	2.29	0.13
Specimen 4	−0.81	0.17	24.01	0.00
Centered noise index	0.00	0.00	0.00	0.98

Estimated Effect (EE), Standard error (SE) oral and maxillofacial (OMF).

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orbital wall fractures.[28] Coronal reconstructions contribute to the diagnostic process of maxillofacial fractures.[28,29] Furthermore, volume rendering CT recreates the surgeon's complex mental process of visualizing fractures in operative planning.[29] Volume rendering does not only give a more accurate diagnostic reading of radiographs, surgeons value it as a front line tool in the evaluation and management of acute facial trauma.[15] However, experienced radiologists and OMF surgeons continue to prefer and interpret 2D CT.[11] MPR and volume rendering can be seen as a valuable addition when choosing CT as primary diagnostic modality. Therefore, we expect that the use of MPR and volume rendering would result in an even a higher actual CT preference in clinical practice than demonstrated in this experimental study. As the current study design does not take into account the full range of CT imaging applications, further research is required to strengthen the evidence base for using CT over DR.

Although DR may still be preferred to assess anatomic integrity after facial trauma, evidence to support the use of CT to diagnose bone trauma increases, especially if a zygomatic trauma is part of the differential diagnosis.

It has been demonstrated that when choosing CT no additional radiographic imaging is needed, while patients often need additional facial imaging following DR. Therefore, the use of CT as primary diagnostic tool reduced facial imaging and as a consequence, radiation dose.[2] However, DR images may well be preferred in situations in which pre- and post-operative evaluation is required.

In addition to the decrease in additional imaging when choosing CT as primary diagnostic tool, several other advantages have been described previously.[1,2,13,23] CT requires considerable less time and can be performed with less potentially hazardous positioning of injured patients as compared to DR.[2,13] As manipulation of the head in the unconscious multi-trauma patient is not advisable, CT is safer and more comfortable for the patient.[2,14] Maxillofacial fractures are often associated with brain injury and/or edema. Therefore, a major benefit of CT over DR is that CT enables assessment of fractures despite the presence of edema, of injuries involving the brain, eyeballs, optic nerves and other soft tissue structures.[13,23–25] Concerning diagnostic accuracy, it has been demonstrated that facial CT imaging is more accurate compared to DR, as CT is superior in displaying fracture lines and the orientation of fracture fragments.[13] Tanrikulu et al. found no significant difference between axial CT, coronal CT and DR for the diagnosis of zygomatic fractures when assessed independently by two examiners.[9] Nevertheless, CT was preferred because of two reasons. First, the exact diagnosis of displacement of each of the five major articulations of the zygoma can be better evaluated which facilitates the selection of the best surgical approach.[26] Second, depression of the zygomatic arch may trap the coronoid process of the mandible and this complication is more easily appreciated using CT.[27]

In conclusion, the current study shows that low dose CT images are preferable over DR images for the assessment of isolated zygomatic fractures. Although the scope of this study was limited due to its design, the results add to an increasing amount of evidence on the advantages of CT over DR. The data presented in this study justifies more research into the use of low dose CT as primary diagnostic tool for the assessment of zygomatic fractures.

Conflict of interest statement

None.

Acknowledgements

Many thanks to Klaas van Linschoten and Janniko Georgiadis from the section anatomy from the department of neurosciences of the University Medical Center Groningen for their collaboration on the human cadavers. Also we would like to thank Jaron McIvor of ScoCode for his contribution by programming the comparison software. Finally, we would like to thank Peter Hogg from the Centre for Health Sciences Research, University of Salford, Manchester, United Kingdom, for critically reviewing the manuscript.

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