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Facial Trauma and 3-D Reconstructive Imaging: Insufficiencies and Correctives

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Purpose: To address the clinical relevance of and optimal technique for 3-D CT imaging of facial trauma. **Methods:** Bioengineered cadaveric models were developed to enhance the concepts of LeFort. Diverse CT imaging techniques were applied to obtain optimal data sets for processing on various 3-D workstations. The fidelity of the 3-D reconstructions was determined by comparison with photographs of the cadaveric models. Optimized 3-D images were then used in conjunction with the initial 2-D data sets to assess whether additional accuracy was contributed by the 3-D images in the evaluation of modeled facial fractures. **Results:** Image definition was heavily dependent upon the specific 3-D reconstruction algorithm and the processor utilized. Orbital fractures were best imaged when 1- to 1.5-mm coronal sections were processed on an advanced 3-D workstation. The 3-D CT images resulted in additional accuracy in the 2-D CT evaluation of facial fractures in 29% of trials. **Conclusions:** We believe that bioengineered models of facial trauma—matched with appropriate CT scanning parameters—facilitate graphically reliable 3-D reconstructive imaging. 3-D reconstructions can improve accuracy in the 2-D CT evaluation of facial trauma.

Index terms: Models, anatomic; Computed tomography, 3-D; Face, trauma

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Rene LeFort revolutionized the understanding of how facial fractures occur by modeling them and determining the stress sites (1). Since then, computed tomography (CT) has become the primary imaging modality for facial fractures with direct primary plane and (indirect) multiplanar reconstructions important for conceptualizing deranged facial morphology. Indirect reconstructions have been, perhaps, more important to the surgeon than to the radiologist. The more complex both the fracture and deranged planes are, the more valuable the faithful multiplanar reconstructions are likely to be for all parties. However, 3-D reconstructional displays have not acquired a significant position in the diagnosis of facial

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trauma because of their inaccuracies and associated artifacts.

The most graphic clinically applicable display of bone morphology is 3-D. Gross pathologic disorders typified by craniofacial anomalies have been accurately and very graphically illustrated by 3-D imaging (2). This has not applied, however, to representing finer anatomic details where 3-D CT imaging of facial trauma has lacked accuracy. Our present investigation has a twofold purpose—first, to investigate those factors that can optimize the accuracy of 3-D images of facial trauma and second, to assess whether these 3-D images contribute significantly to the routine 2-D CT evaluation of facial trauma.

Materials and Methods

Three cadaveric heads were obtained from the Department of Anatomy for the purpose of creating models of commonly occurring facial fractures. The fractures which were programmed included LeFort, tripod, orbital blowout, and multiple comminuted orbital fractures with distractions ranging from zero to several millimeters. Two methods of loading were used to produce fractures in cadavers in vitro.

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Fig. 1. A, Photograph of a cadaver containing a comminuted right orbital fracture. Numbers (1, 2, 3) show different components of the orbital roof and lateral orbital fractures. The posterior orbital fracture with its medial extension (4) is seen.

B, Photograph of the same cadaver as in A showing the "zig-zag" fracture of the right orbital floor (dashed lines).

C, Photograph of the contralateral orbit showing a comminuted left orbital floor fracture with one prominent fracture (arrowheads), as well as an inferior orbital rim fracture (dashed black lines).

D, Axial acquisition with 1.5-mm section thickness, seed growing algorithm (ISG). Right orbital roof and lateral wall fractures (2, 3) are only partially identified. Bone loss from the orbital roofs is due to a combination of partial volume averaging and thresholding effects. Bilateral zygomatico maxillary region fractures (X and Y) are well seen.

Loading Technique One

In this, our initial loading technique, a 98-N (see Appendix) weight was dropped a distance of 1.42 meters to produce a midface fracture over a relatively large area. The energy of this loading was 139.4 N-m, with a velocity at impact of 4.43 m/sec. The total area affected by this impact loading was approximately 10 cm². The fractures produced involved the midface (cadaver 3, Fig. 1) and the zygoma (cadaver 2, Fig. 2) with concomitant fractures of the orbital regions.

Loading Technique Two

This technique, which was more precise, provided a more concentrated load on a specific region of the face. The impact device used had been developed for inducing signal burst fractures (3-5). Cadaveric specimens were secured to the device and positioned for load application to produce either LeFort or zygomatic fractures. The head was supported rigidly by a support block and the face was exposed to impact loading from above. The impact force was generated by a weight dropped along a guide rod and



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Fig. 1.-Continued. E, Coronal acquisition with 1.5-mm section thickness, seed growing algorithm. Right orbital roof and lateral orbital fractures (1-3) are better displayed than in D. Posterior orbital fracture (4) is partially identified. Bilateral zygomaticomaxillary region fractures (X and Y) are, again, well displayed.

F, Axial acquisition with 1.5-mm section thickness, seed growing algorithm. Note significant "dropout" (D) of bone from the orbital floors as a result of partial volume averaging and thresholding effects, possibly compounded by the orbital floor fractures.

G, Coronal acquisition using 1.5-mm section thickness, seed growing algorithm. Right zig-zag orbital floor fracture is well seen (dashed lines) along with the normal bone of the orbital floor. The left orbital floor fracture is also identified (arrowheads). A left infraorbital rim fracture is present (single small black arrowhead.)

H, 2-D coronal section shows bilateral facial fractures, including right orbital floor fracture (white arrowheads).

was applied through a circular region of contact measuring 10.2 cm².

The load conditions in this second technique were scaled from the first series of tests based on the energy applied per unit area. In the first series of tests, the energy per area was 130K Nm/m². For the more focused loading, a similar energy per area value was selected that gave a value of about 50-Nm for the impact energy. This load condition



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Fig. 2. A, Photograph of the cadaveric specimen containing a left tripod fracture and orbital wall fractures. Multiple fracture fragments (1, 2, 3) are seen in the orbital floor as well as in the medial orbit (4).

B, The lateral orbital wall fracture (large arrowheads) and posterior orbital wall fractures (small black arrowheads) with its lateral extension (white/black arrowheads) is seen. A second orbital fracture is labeled (white arrow).

C, Axial acquisition with 1.5-mm section thickness, seed growing algorithm. There is some loss of bone from the orbital floors. Large black arrowheads indicate the lateral orbital fracture on the left. Fracture of the posterior orbit is not identified.

D, Coronal acquisition with 1.5-mm section thickness, seed growing algorithm. Fractures of the lateral (large arrowheads), posterior (small arrowheads) and medial orbital wall (4), and of the orbital floor (1, 2, 3) are seen.

was produced by specifying the height for dropping a 100-N weight. For these tests, the 100-N mass was dropped from a 0.5-meter height along the guide rod, with the resultant potential energy of 50 N-m. The impact velocity was 3.1 m/sec using this drop weight. This method of loading created localized fractures of the facial bones, without the accompanying comminuted fractures of the orbital regions.

The orbital blowout fracture was created by blunt trauma to the inferior orbital rim as illustrated by Nesi et al (6) (cadaver 1, Fig. 3).

CT Data Acquisition

All cadaveric specimens were imaged in a GE 9800 CT scanner (General Electric, Milwaukee, WI) using serial, contiguous, nonoverlapping 1.5-mm sections. Technical factors were 120 kVp, 140–170 mA, pulse width of 2 seconds, an 18-cm display field of view, matrix size of 512 × 512 and the bone reconstruction algorithm. Three angles of scanning were used: 0°, 45°, and 90° to the hard palate. The cadaver containing the orbital blowout fracture (Fig. 3), was initially scanned on the GE 9800. Thereafter, a depressed contralateral tripod fracture was created using the impact device of Edwards et al (4). These two fractures were scanned by both axial and coronal 1-mm sections on a Siemens Somatom Hi-Q CT scanner (Siemens Medical Systems, Iselin, NJ). Technical factors were 133 kVp, 190 mA, pulse width of 2.7 seconds, matrix size of 512 × 512 and the "ultrahigh" algorithm.

3-D Imaging

Three 3-D imaging systems were used to generate the 3-D images. Those images obtained on the GE 9800 scanner were initially processed on a GE independent console on the 3-D 98 Quick software at a threshold value of 200. Siemens routine 3-D software was used to generate the initial 3-D images from those obtained from Siemens Somatom Hi-Q scans; a threshold value of 225 was initially

utilized in these reconstructions. Illumination algorithms were planar depth shading for the GE 3-D 98 Quick and variable point source for the Siemens 3-D system. Then both the GE and Siemens scanner image data was processed using the ISG Camra Allegra dedicated 3-D workstation. 3-D reconstructions of Siemens image data were processed using a *regional variable threshold/seed growing algorithm* for the right orbital blowout fracture and using the *binary thresholding algorithm* for the remainder of the face.

The ISG reconstructions from the GE data were generated using a regional variable thresholding/seed growing algorithm. *An ISG surface enhancement algorithm* was also used to modify selected images generated from the coronal 1.5-mm GE 9800 image data and from selected Siemens image data. A multiple variable point source and variable depth shading illumination algorithm was utilized for the ISG-generated 3-D images.

All 3-D CT images were generated independent of cadaver model photographs. The 3-D images were correlated with photographs to assess the accuracy of each imaging technique (slice thickness, angle of section) and 3-D processing system. Fracture displacement, distraction, and comminution were evaluated. The most accurate ("opti-

Fig. 3. The following symbols and letters apply to all figures: *PO*—greater sphenoid wing (posterior orbital wall); *black arrows*—laterally located orbital floor fracture; *white solid arrows*—medial border of a "stellate" orbital floor fracture; *open arrows*—displaced lateral infraorbital rim fracture.



A, Photograph of a cadaveric specimen showing a displaced right infraorbital rim fracture (*open arrows*), lateral orbital floor fracture (*black arrows*), and medial border of a "stellate" orbital floor fracture (*white arrows*).

B, 3-D CT reconstruction, axial acquisition, and 1.5-mm section width, seed growing algorithm. The orbital floor fractures are not identified. "Dropout" (*D*) in the orbital floor is a result of partial volume averaging and thresholding effects.

C, Coronal acquisition and 1.5-mm section thickness, seed growing algorithm. The lateral orbital floor fracture (*arrowheads*) is well visualized. "Dropout" (*D*) in the orbital floor is present so that the stellate fracture is not seen.

D, Coronal acquisition with 1-mm section thicknesses, seed growing algorithm. Portions of the orbital floor fractures (*black and white arrows*) are seen. There is no "dropout" of bone in the orbital floor. *Dashed black lines* indicate the posterior portion of the lateral orbital floor fracture that is not visualized.

E, Coronal 1.5-mm 2-D CT image showing right orbital rim (*white arrowhead*) and orbital floor (*white arrow*) fractures.



mized") 3-D images for each cadaveric model were selected by the authors (R.A.L., A.E.R.) for the purpose of comparison with corresponding 2-D images. Eight observers, including three neuroradiologists, one second-year fellow in neuroradiology, three board-certified general radiologists, and one senior radiology resident (entering a neuroradiology fellowship) evaluated each of the paired 2-D and 2-D/ 3-D sets of images for each of the three cadavers. The observers were asked to draw their impressions of the locations of the facial fractures on a standardized diagram using only the 2-D CT images. The observers were then asked to repeat this evaluation using both 2-D and 3-D CT data sets. The paired 2-D and 2-D/3-D evaluation forms were evaluated by us (R.A.L., J.R.M.) for each case and each observer by comparing them with the cadaveric specimen photographs. We determined whether the 3-D images added significantly to the accuracy of the observations. The 2-D/3-D interpretations were judged to add accuracy to the "2-D only" interpretations when a fracture not seen on "2-D only" was detected by the 2-D/3-D combination, or when a "false positive" fracture seen on "2-D only" data was not detected on 2-D/3-D.

Results

Cadaver 1 with the right orbital blowout fracture afforded the opportunity to compare the most diverse set of imaging techniques, software, and reconstruction algorithms. Special attention was focused on the analysis of the normal orbit and orbital fractures since there was a large number of orbital fractures present in our three cadavers.

The most accurate 3-D reconstructions of the right orbital blowout fracture occurred using 1mm contiguous coronal sections processed via a regional thresholding/seed growing (ISG) 3-D reconstruction algorithm. (Fig. 3). There was only partial visualization of the orbital floor fractures when 1.5-mm coronal sections were utilized in conjunction with the regional thresholding/seed growing algorithm (ISG). However, unlike the coronal scan orientation, utilization of the axial scanning orientation failed to image orbital floor fractures. When using the Siemens 3-D binary thresholding algorithm, the orbital floor was well imaged on the 1-mm coronal sections, but no fractures were visualized.

Other midfacial fractures, such as LeFort and tripod fractures, although demonstrable, were few in number and, therefore, not systematically studied (Figs. 1 and 2). Our results suggest that it is likely that CT scan orientation becomes less significant in the accurate 3-D display of nonorbital facial fractures when 1-mm sections are used. These fractures were used, however, in the 2-D and 2-D/3-D comparison portion of the experiment.

The results of our assessment of the increased accuracy in the interpretation of 2-D CT images of facial trauma afforded by the addition of 3-D reconstructions are presented in Table 1.

Of the 24 possible case/observer responses, 7/24 (29%) showed increased accuracy in interpretation of the 2-D CT images when 3-D was used concurrently. Observers no. 1 (neuroradiologist), no. 4 (general radiologist), and no. 6 (fourth-year radiology resident/neuroradiology fellow) each developed more accurate descriptions of the facial fractures when 2-D and 3-D images were used versus 2-D images alone. Essentially, the three cases were equally represented when the 2-D/3-D combination yielded greater accuracy in interpretation than 2-D alone—case no. 1—2/8 (25% of total possible), case no. 2—2/8 (25% of total possible), case no. 3—3/8 (37.5% of total possible).

Discussion

Rene LeFort was the innovator of a systematic approach to creating facial trauma in cadavers (1). His technique involved the dropping of blocks on immobilized cadaveric heads and more aggressive methods, such as throwing entire corpses face first against blunt objects. The forces or impact energies generated in these experiments were not quantified by LeFort.

A previous simplified modeling of fractures in a dried skull has been described in which clinical type fractures were created with a handsaw (7). In this experiment, we sought to reexamine Le-Fort's techniques of blunt trauma. Initially, cinder blocks were dropped on an immobilized cadaveric head. Although this technique produced the desired fracture types, the energy dissipated on the cadaveric face from the dropped blocks also produced multiple comminuted hairline fractures.

TABLE	1:	2-D	vs 2-D	/3-D	in	evaluating	CT	image	accuracy
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Obse	Observer		Case No.				
N	D.	1	2	3			
1		+	+	-			
2	2	_	-	-			
5	3	_	-	+			
4	1	+	_	+			
5	5	-	-	_			
e	5	-	+	+			
7	,	-	_	-			
8	3	-	-	_			

Note.—+ = 3-D adds to accuracy of 2-D; - = 3-D does not add to accuracy of 2-D.

To control the fracture types within a confined region to those encountered clinically, the technique of Edwards et al (4) was used.

The severity of fractures observed in the present study varied according to the applied impact energies which ranged from 139 N-m to 50 N-m, with impact velocities between 3–4.5 m/sec. At the higher energies, midface, zygomatic fractures and orbital region fractures occurred. At lower impact energies, the extent of fractures could be confined. This suggests that this range of testing conditions may be representative of injury conditions in vivo. Additional investigations are needed to determine the effect of variations introduced by differences in facial geometry, bone structure, and other parameters known to influence bone strength.

In this experiment, we have approached the imaging problem of minimizing inaccuracies resulting from partial volume averaging by controlling data acquisition and postprocessing of the image. Partial volume averaging was minimized by using the smallest slice thickness possible (1.5)mm for the GE 9800 and 1 mm for the Siemen's Somatom Hi-Q), creating voxels that approach isotropy. When CT scan orientation is altered, partial volume averaging effects will occur if anisotropic voxels are present. The utilization of a variable thresholding 3-D reconstruction algorithm permits the operator to regionally lower the threshold values so that voxels of a particular tissue type (eg, bone) which have been volumeaveraged are still included in the data set used for the 3-D reconstruction. The pitfall of this methodology is that the threshold value may be excessively lowered in the region of interest so that tissue of undesired Hounsfield unit value (eq. soft tissue) is included in the 3-D reconstruction. A solution to this problem can result when the operator draws a region of interest around a specific anatomic structure (eg, lamina papyracea) and manually lowers the threshold value until the region of interest is literally "filled in" (often slice by slice) to afford inclusion by the 3-D reconstruction algorithm. In this circumstance, however, pathology may be missed because of "fill in." By acquiring an optimal 2-D CT data set which combines the appropriate slice thickness and scan angle, partial volume averaging in the initial 2-D data set is minimized and postprocessing inaccuracies (eg, corrections for partial volume averaging, produced by thresholding errors) are reduced. Thus, "pseudoforamina" and errors of inclusion in the 3-D reconstructions may result from the combination of suboptimal 2-D data acquisition and thresholding errors. A discussion of investigational work underway to minimize effects of partial volume averaging by advanced thresholding algorithms has recently been reported (8). While a completely automated 3-D thresholding algorithm would be ideal, or artificial intelligence review would appear valuable, the current dependence of results on a user-interactive seed growing algorithm to detect fine details is still necessary. The surface-enhancement algorithm further provided improved visualization of facial fractures. This improved visualization was not based upon changes in thresholding, but rather on modifications in surface illumination.

It is obvious to the practicing radiologist that the acquisition of numerous serial 1-mm sections (axial or coronal) is very difficult to obtain in the acutely traumatized patient who is combative or uncooperative. A high-resolution study presently requires 45-60 minutes for approximately 100 1.5-mm slices. Even when the patient returns for a subsequent CT data acquisition for 3-D, patient motion must be minimized. Furthermore, scanning speed and table incrementation of present CT scanners can lend themselves to slice misregistration that transforms into "step" artifact and error on the resulting 3-D reconstructions. Software that allows for manual realignment of misregistered CT slices is not known to exist presently. Solutions to improving 3-D reconstructions include more reliable and comfortable head restraints, patient sedation, and (ultimately) fast scanning.

3-D reconstructions formerly were relatively time consuming (1–2 hours long). Even with tape transferring from CT to the 3-D workstation, images on advanced systems can now usually be loaded and processed in 5–10 minutes. Thus, clinical use and radiologist-surgeon interaction at the 3-D workstation can transpire. What is obviously pertinent is that the CT scanner images rapidly, sufficiently thin sections are generated, the correct scan angle is used, and the appropriate algorithm is selected to optimize imaging results.

Comparing 2-D and 3-D

In the present study, we determined that 3-D images add significantly to the 2-D CT evaluation of severe facial trauma in 29% of trials. The observer level of training, as well as type of facial fractures studied, did not bias this result. The

figure of 29% is conservative and would be expected to increase with improvement in physician training in the evaluation of 3-D images.

At present, it is unlikely that 3-D CT images will replace the routine 2-D CT evaluation of facial trauma. However, it is foreseeable that with the appropriate combination of 2-D data (eg, 1-mm coronal sections), CT scanner (eg, fast scanner) and 3-D workstation, 3-D images of sufficient accuracy to significantly enhance the 2-D CT interpretation of severe facial trauma will become routinely utilized. The added understanding provided by accurate 3-D CT images remains unquantified primarily due to lack of physician education in the interpretation 3-D CT images.

We conclude that bioengineered models of facial trauma when matched with appropriate scanning parameters and an advanced 3-D workstation provide graphic reliable imaging. 3-D reconstructions can improve the accuracy of routine 2-D CT evaluation of facial trauma, elevating the importance of 3-D from an interest of referring physicians to being relevant for neuroradiologists and head and neck radiologists.

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APPENDIX

Glossary

- Binary thresholding—input of the same threshold value for each 2-D CT slice in the 3-D reconstruction volume.
- Newton (N)—unit of force = $1 \text{ kg} \text{m/sec}^2$, where kg = kilogram and m = meter.

N-m—Newton-meter = unit of energy.

- Seed growing—user-interactive process by which a threshold value is specified and every voxel above that threshold within a predetermined anatomic region is included.
- Threshold value—Hounsfield unit value below which voxels are not included in the 3-D surface reconstruction.
- Variable thresholding—user-interactive process by which the threshold value may be changed on a (CT) slice by slice basis or regionally within a (CT) slice.
- Partial volume averaging—effect of inhomogeneous tissue types within an imaging volume on the Hounsfield unit value of an imaging volume (eg, a voxel).

References

- LeFort R. Etude experimental sur les fractures de la machoire superieure. Revue De Chirugie 1901;23:360–379
- Vannier MW, Marsh JL, Warren JO. Three dimensional CT reconstruction images for craniofacial surgical planning and evaluation. *Radiology* 1984;150:179–184
- Fredrickson B, Yuan H, Miller H. Burst fractures of the fifth lumbar vertebra. J Bone Joint Surg 1982;84(A):1088–1094
- Edwards WT et al. Biomechanical assessment of burst fractures in the thoraco-lumbar spine. Presented at the 1991 meeting of the Orthopedic Research Society.
- Fredrickson BE et al. Reduction of the intracanal fragment in burst fractures. Presented at the Second Annual Meeting of the North American Spine Society, 1987
- Nesi F, LiVecchi J, Mathog RH. Orbital blowout fractures. In: Mathog RH, ed. *Maxillofacial trauma*. Baltimore: Williams and Wilkins, 1984: 322–323
- Levy RA, Rosenbaum AE, Kellman RM, Bailey GL, Aravapalli SR. Assessing whether the plane of section on CT affects accuracy in demonstrating facial fractures in 3D reconstruction using the dried skull. *AJNR* 1991;12:861–866
- Kohn MI, Nitin TK, Herman GT, et al. Analysis of brain and cerebrospinal fluid volumes with MR imaging. *Radiology* 1991;178:115–122

Please see the Commentary by Zinreich on page 893 in this issue.