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Assessing Whether the Plane of Section on CT Affects Accuracy in Demonstrating Facial Fractures in 3-D Reconstruction When Using a Dried Skull

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CT slice thickness and threshold value are well-known determinants of accuracy in three-dimensional (3-D) CT image reconstruction. The purpose of this study was to assess whether the plane selected for primary CT data acquisition, axial vs coronal, might also contribute to the accuracy and ease of identification of abnormalities in 3-D image reconstruction independent of the 3-D processing system used. Two sets of 10 observers evaluated fractures created in a dried skull and corresponding 3-D image data. A General Electric 9800 scanner was used to acquire the two-dimensional CT data. The 3D98 Quick software and ISG Camra Allegra workstation were used for two sets of 3-D reconstructions. The expected result was that fractures oriented perpendicularly to the initial plane of CT section would be better reconstructed on 3-D than when the initial plane of CT imaging paralleled the fracture.

Our results indicate that Le Fort fractures (types I and III) are better displayed with coronal CT data and that zygomatic tripod fractures may be better displayed in 3-D with axial CT image data.

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While the usefulness of three-dimensional (3-D) CT imaging as a method of display is well known, it is slowly being accepted as a routinely used diagnostic imaging technique of fidelity and accuracy equal to that of previously established methods. Moreover, it is frequently found to be more helpful to referring physicians, especially surgeons, than to radiologists. Of the many variables that determine accuracy in 3-D CT imaging, the primary CT scan orientation for acquisition of two-dimensional (2-D) CT data has received scant attention as a significant determinant of the accuracy of 3-D images [1]. To systematically study facial fractures, we examined three planes of serial sections (0°, 45°, and 90° to the hard palate) in relation to a dried skull model in which numerous fractures were created. It was our purpose to determine whether, from the dried skull model, the 3-D imaging of facial trauma might benefit from preselecting the CT plane of section from the clinical, preradiologic identification of fractures or from fractures suspected on plain skull films.

Materials and Methods

Nine distinct facial fractures were created in a dried skull by using a hand saw. Most fractures were designed to be nondisplaced with orthogonal components. Most fractures in the dried skull were minimally distracted (1–2 mm) without displacement, an advantage of using the dried skull model over in vivo conditions, where fracture distraction/displacement may be more pronounced and, therefore, more readily detected. Of the nine dried skull fractures, multiple planes were involved in eight and a significant amount of displacement (5- to 6-mm depressed right orbital floor fracture) in one. The fracture design focused on familiar clinical fractures; for example, tripod and Le Fort I, II, and III types. For examination constancy, the skull was scanned in a water bath [1] at contiguous 1.5-mm intervals by using a GE 9800

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scanner; WB version software; technical factors of 120 kVp, 170–200 mA, 2-sec pulse width, 18-cm display field of view, and 512 × 512 matrix; and the "standard" reconstruction algorithm. Axial, coronal, and intermediate (45° between the axial and coronal) CT scans were obtained, following which 3-D image reconstructions were generated. The axial plane was parallel to the hard palate; the coronal plane was perpendicular to the hard palate.

The GE 3D98 Quick software and ISG Camra Allegra workstation were used for two sets of 3-D reconstructions. A threshold value of 200 was used for all 3-D CT images generated on the 3D98 Quick software. For the ISG-generated 3-D images, a seeded volume-of-interest technique with variable threshold levels was used. Ten physicians, comprising three neuroradiologists; two general diagnostic radiologists; one neuroradiology fellow; two otolaryngologic surgeons; and two senior residents in diagnostic radiology, evaluated each fracture on the dried skull in conjunction with the 3-D CT images generated from the 3D98 Quick software and judged which plane of initial CT section best described the fractures. A second group of 10 physicians, comprising four neuroradiologists; one neuroradiology fellow; three radiologists; and two otolaryngologic surgeons, evaluated the ISG-generated 3-D images in conjunction with photographs of the dried skull with fractures labeled as in Figures 1A and 2A, again to assess which plane of CT section resulted in the most accurate 3-D images.

Results

Table 1 demonstrates the number of observers selecting either the axial, coronal, or intermediate scan orientations as best demonstrating the specific components of each of the nine fracture complexes for the GE 3D98 Quick processing system or the ISG Camra Allegra workstation. *Vertical* and *horizontal* components of a fracture complex were determined by topography. Thus, the vertical component of a fracture complex was perpendicular to the plane of the hard palate, whereas the horizontal component was parallel to the plane of the hard palate. In some fracture complexes, multiple components were confined within one plane relative to the hard palate. In such instances, both components of the fracture are indicated (e.g., the anterior and posterior components of a horizontally oriented Le Fort I fracture, Fig. 1A). A maximum of 10 observations per fracture component was possible. Thus, if a fracture complex had two components, 20 observations would result. In our process of gathering responses from the 10 observers, there were instances in which the observer was unable to choose a scan orientation that best displayed a given fracture component in 3-D. In such instances, the observer selected more than one scan orientation for a given fracture component, resulting in more than 10 observations for this fracture component.

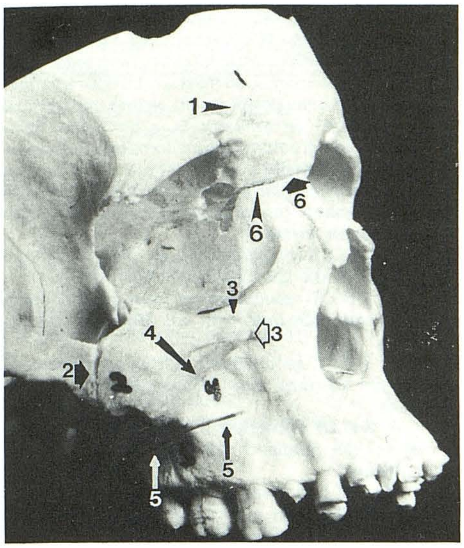
For the 3-D images generated by the GE 3D98 Quick system, the intermediate (45°) scan orientation was not chosen as offering the best visualization of a fracture component in any of the nine fracture complexes (Fig. 1C). The horizontal frontoethmoidal fracture (Le Fort III) was best displayed on the 3-D images reconstructed with the coronal scan plane—20 of 20 observations (Fig. 1D). Horizontal maxillary fractures (Le Fort I) were displayed least well with axial scanning data—one of 30 observations (Fig. 1B). A zygomatic arch fracture was best demonstrated with the axial acquisition—18 of 20 observations; a depressed (right) orbital floor/rim fracture was displayed least well with the coronal data set—one of 20 observations (Figs. 1D and 2C). No other fracture complexes were better displayed in 3-D when one 2-D acquisition plane was compared with another. However, components of certain fracture complexes were better displayed when CT scan orientation was varied. These were the vertical component of a supraorbital rim fracture, where the axial plane was least preferred—one of 10 observations (Fig. 1B); the posterior component of a right zygomaticomaxillary suture fracture (Le Fort type II or tripod), where the coronal plane was least preferred—one of 10 observations; the vertical component of a left orbital floor/infraorbital rim fracture, where the coronal plane was least preferred—one of 10 observations (Fig. 2C); for its horizontal component, the axial plane was preferred least—one of 10 observations (Fig. 2B).

For the ISG Camra Allegra workstation, the intermediate scan orientation was not chosen as offering the best visualization of a fracture component in any of the nine fracture complexes on the 3-D reconstructions (Fig. 1F). The horizontal frontoethmoidal fracture (Le Fort III) was best displayed on the 3-D images reconstructed by using the coronal scan plane—17 of 20 observations (Fig. 1G). Horizontal maxillary fractures were displayed least well in 3-D with axial data—0 of 31 observations (Fig. 1E). A right zygomatic arch fracture was best displayed in 3-D with axial data—16 of 24 observations (Fig. 1E). No other fracture complexes were better displayed in 3-D, despite the horizontal component of a left orbital floor fracture complex being least well displayed with axial data—0 of 10 observations (Fig. 2D). These results are displayed in Table 1.

A comparison of the results in Table 1 indicates that the axial scan orientation was preferred in generating 3-D CT images of the right zygomatic arch fracture and the coronal scan orientation was preferred in generating 3-D CT images of the frontoethmoidal Le Fort III fracture, regardless of the processing system used (GE vs ISG). Similarly, the lack of preference for the axial scan orientation in generating 3-D CT images of horizontal maxillary fractures of a Le Fort I type was independent of the 3-D system used. The horizontal component of the left orbital floor/infraorbital rim fracture complex was also better displayed in 3-D with scan orientations other than axial. This result was, again, independent of the processing system used. Of note, while the coronal scan orientation was least preferred in the 3-D reconstruction of a depressed right orbital floor fracture when the GE 3D98 Quick software was used, this result was not observed when the ISG Camra Allegra workstation was used.

Discussion

The aesthetic and diagnostic appeal of 3-D reconstructed CT images has been overshadowed by exhortations from surgeons for improved image fidelity [2]. We undertook our study from the vantage point of data acquisition rather than from postprocessing of the image. We assumed that reduction of effects from partial-volume averaging of the type seen on 2-D CT images would facilitate accurate 3-D display when



A

Fig. 1.—*A*, Dried skull. Numbering system applies to same fractures in *B–G*: 1 = right supraorbital rim fracture, vertical component; 2 = right zygomatic arch fracture, vertical component; 3 = depressed right orbital floor fracture, horizontal component (*arrowhead*) and vertical component (*open arrow*); 4 = right zygomaticomaxillary suture fracture, anterior component (barely perceptible, *black arrow*); 5 = right horizontal maxillary fracture, anterior component (*black arrow*) and posterior component (*white arrow* in *A*; *arrowhead* in *C*); 6 = horizontal frontoethmoidal fracture, lateral component (*arrowhead*) and anterior component (*arrow*).

B, Three-dimensional (3-D) CT reconstruction of dried skull derived from axial plane of section by using GE 3D98 Quick software. Note that right horizontal maxillary fracture is not detected. Vertical component of right zygomatic arch fracture (2) appears equally displayed on *B–D*, but observers selected axially derived 3-D image as best depiction of this component.

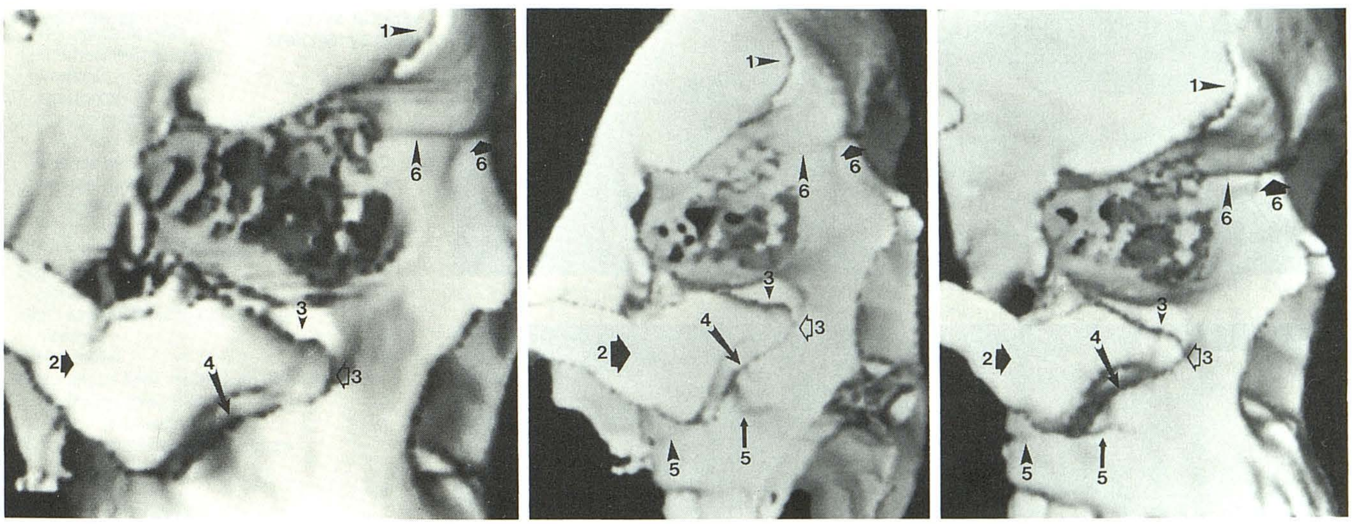
C, 3-D CT reconstruction from intermediate (45° angulation to coronal and axial) plane of section using the GE 3D98 Quick software. Right horizontal maxillary fracture (5) is now appreciated.

D, 3-D CT reconstruction from coronal plane of section obtained with GE 3D98 Quick software. Horizontal frontoethmoidal fracture (6) is best displayed on this image. Right horizontal maxillary fracture (5) is also visualized.

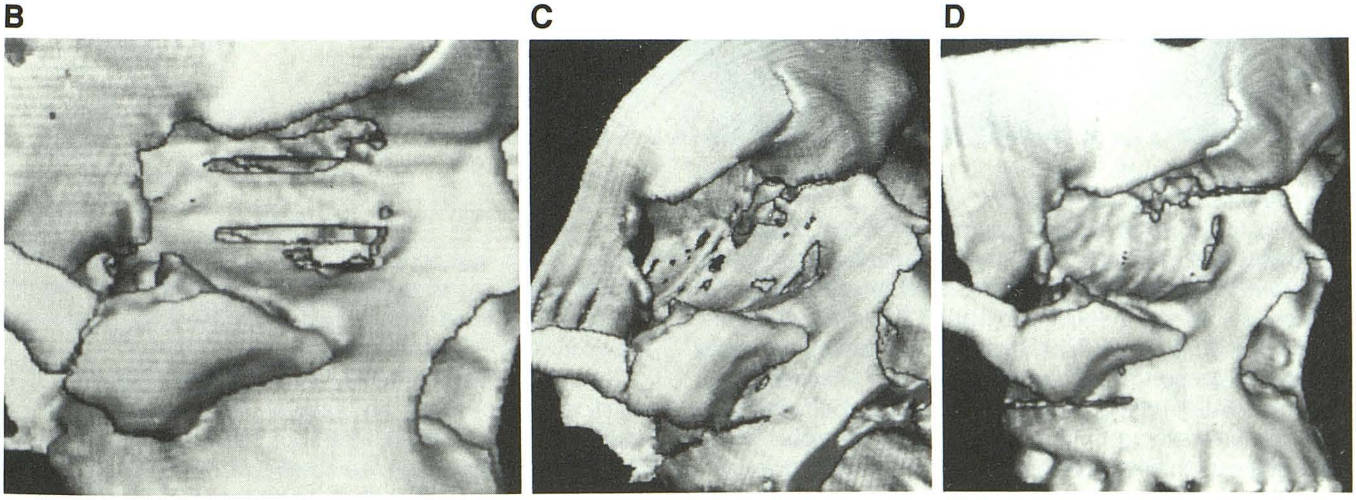
E, 3-D CT reconstruction of dried skull derived from axial plane of section with ISG workstation and software. Note that right horizontal maxillary fracture is not detected, as in *B*. However, vertical component of right zygomatic arch fracture is best seen on this image and is better seen than on axial 3-D reconstruction from GE 3D98 Quick software.

F, 3-D CT reconstruction from intermediate (45° angulation intermediate to coronal and axial) plane of section obtained with ISG software and workstation. Right horizontal maxillary fracture is appreciated and is better seen than on comparable 3-D reconstruction from GE 3D98 Quick software.

G, 3-D CT reconstruction from coronal plane of section obtained with ISG workstation and software. Horizontal frontoethmoidal and right horizontal maxillary fractures are displayed to a similar extent as in *F* and better than in *E*. Fractures are seen better by ISG than by GE system.



B C D



E F G

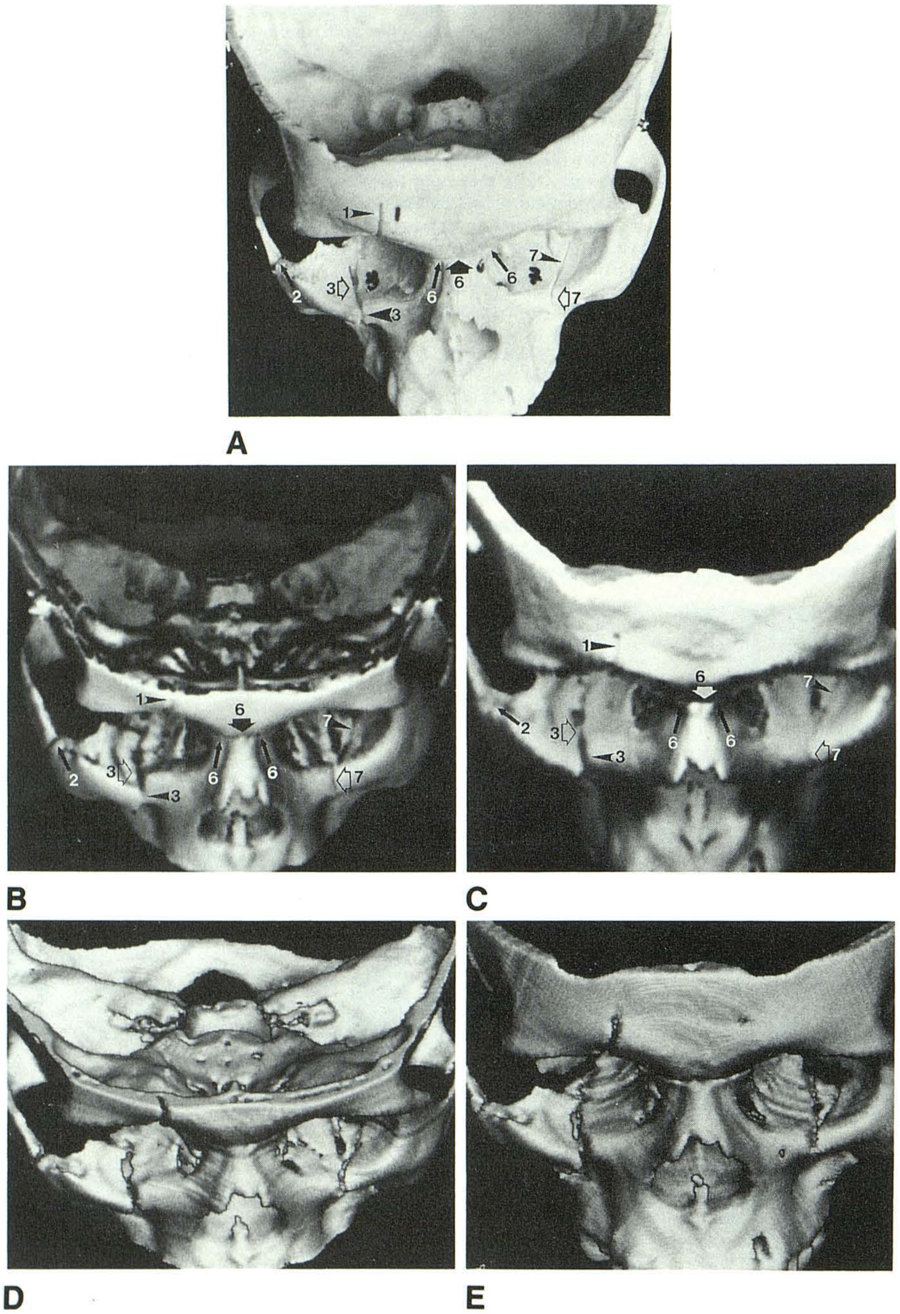


Fig. 2.—*A*, Dried skull. Numbering system applies to same fracture types in *B–E*: 1 = right supraorbital rim fracture, vertical component; 2 = right zygomatic arch fracture, horizontal component; 3 = depressed right orbital floor fracture, horizontal component (*open arrow*) and vertical component (*arrowhead*); 6 = horizontal frontoethmoidal fracture, lateral component (*long arrows*) and anterior component (*short arrow*); 7 = left orbital floor/infraorbital rim fracture, horizontal component (*arrowhead*) and vertical component (*open arrow*).

B, 3-D CT reconstruction of dried skull from axial data and GE 3D98 Quick software.

C, 3-D CT reconstruction from coronal plane of section obtained with GE 3D98 Quick software.

D, 3-D CT reconstruction from axial plane of section obtained with ISG workstation and software.

E, 3-D CT reconstruction from coronal plane of section obtained with ISG workstation and software.

Overall there was no preference for axial or coronal CT scan orientation in generating 3-D images of orbital floor fractures. Note that there was a preference for noncoronal scan planes in 3-D reconstruction of right orbital floor fracture with GE system. This finding was not corroborated by ISG data.

standard thresholding algorithms were used. It is known that thin CT slices result in reduced partial-volume averaging and increased accuracy in 3-D CT imaging [1]. Having observed the effects of reducing CT slice thickness when anisotropic voxels are generated, we hypothesized that changes in CT scan orientation might also result in reduced effects from partial-volume averaging. We observed that the probability of detecting certain nondisplaced, 1- to 2-mm wide fractures on 3-D reconstruction is increased when the plane of 2-D data acquisition is orthogonal to the (long axis of the) fracture. These "optimal" imaging planes, while being orthogonal to the (long axis of the) fracture component, were also orthogonal to the surface of the skull at the fracture site. Thus, choosing the appropriate CT scan angle reduces partial-volume averaging at the fracture site and facilitates the detection of fractures when standard thresholding algorithms are used.

This study has determined that CT scan orientation is a significant factor in the accuracy of 3-D CT images when a dried skull with simulated facial fractures is used as the model. Our results indicate that the coronal plane of section generates 3-D CT images that display components of Le Fort I and III fractures better than when the axial plane of section is used. The results further demonstrate that the zygomatic arch component of a right tripod fracture is better displayed when the axial scan orientation is used for initial data acqui-

TABLE 1: Comparison of Simulated Fractures in a Dried Skull with Three-Dimensional CT Images Obtained with Two Different Three-Dimensional Processing Systems

3-D System/Fracture Complex/ Component	Scan Orientation Best Showing Fracture Component		
	Axial	Coronal	Intermediate
General Electric 3D98 Quick software			
Right supraorbital rim			
Vertical	1	2	7
Horizontal	5	3	2
Right zygomatic arch (tripod)			
Vertical	**10**	0	0
Horizontal	**8**	1	1
Right orbital floor/rim, depressed (tripod)			
Vertical (orbital rim)	5	**0**	5
Horizontal (orbital floor)	5	**1**	4
Right zygomaticomaxillary suture (Le Fort II or tripod)			
Vertical (posterior)	4	**1**	5
Vertical (anterior)	4	6	0
Right maxillary (Le Fort I)			
Horizontal (anterior)	**0**	6	4
Horizontal (posterior)	**1**	4	5
Frontoethmoidal (Le Fort III)			
Horizontal (anterior)	0	**10**	0
Horizontal (lateral)	0	**10**	0
Left orbital floor/infraorbital rim			
Vertical	6	**1**	3
Horizontal	**1**	6	3
Left zygomaticomaxillary suture (Le Fort II or tripod)			
Vertical (anterior)	5	5	0
Vertical (posterior)	5	5	0
Left maxillary (Le Fort I)			
Horizontal	**0**	6	4
ISG Camra Allegra workstation			
Right supraorbital rim			
Vertical	4	6	1[a]
Right zygomatic arch (tripod)			
Vertical	**8**	0	3[a]
Horizontal	**8**	2	3[a]
Right orbital floor, depressed (tripod)			
Horizontal (orbital rim)	3	6	3[a]
Vertical (orbital floor)	4	3	3
Right zygomaticomaxillary suture (Le Fort II)			
Anterior	4	2	5[a]
Right maxillary (Le Fort I)			
Horizontal, anterior	**0**	7	3
Horizontal, posterior	**0**	**9**	1
Frontoethmoidal (Le Fort III)			
Horizontal (anterior)	**0**	**10**	0
Horizontal (lateral)	**0**	7	3
Left orbital floor/infraorbital rim			
Horizontal	**0**	7	3
Vertical	5	4	1
Left zygomaticomaxillary (Le Fort II or tripod)			
Anterior	2	6	2
Left maxillary (Le Fort I)			
Horizontal	**0**	**8**	3[a]

Note.—Numbers in boldface type indicate observers' preference of scan orientation believed to be significant by the authors.

[a] Rows with numbers totaling more than 10 reflect the inability of some observers to select only one response.

sition. This suggests that the axial scan orientation may be better than any other plane of section in the 3-D reconstruction of tripod fractures, since there was no preference for any particular scan orientation (axial, coronal, or intermediate) in the 3-D display of the zygomaticomaxillary or orbital floor components of the right tripod fracture (Figs. 1B and 1E). Our results also indicate that the horizontal component of a left orbital floor fracture was better displayed with scan orientations other than axial for CT data acquisition. Since similar observations were not present regarding the right orbital floor fracture, no definitive preference of scan orientation was made in the display of orbital floor fractures. We note that the lack of preference of the observers for the coronal scan orientation in the 3-D display of a right orbital floor fracture was inconsistent with our anticipated result. An explanation for this lies in the depression of the fracture, which created a fracture surface orthogonal to both the axial and coronal planes and facilitated its detection with both 2-D data sets. It may be that displaced fractures are detected equally when the axial and coronal scanning angles are used and that CT scan orientation becomes significant in the 3-D display of facial fractures primarily when they are nondisplaced.

Although similar results were obtained with the GE and ISG systems, we emphasize that differences in 3-D reconstruction algorithms—that is, fixed binary thresholding for the GE 3D98 Quick system and variable thresholding with seed-growing algorithm for the ISG Camra Allegra system—make exact comparison of the two data sets impossible. For example, close inspection of the GE vs ISG images discloses "filling-in" of pseudoforamina on the ISG images due to the seeded volume-of-interest option (user dependent) that is available with the ISG system (compare the lamina papyracea on images in Figs. 1B and 1E). Note that filling-in of fractures is a potential pitfall of this technique. We did not think that this occurred to any significant extent in this experiment.

We have demonstrated that CT scan orientation plays a significant role in the generation of 3-D images when a dried skull with simulated fractures is used as a model. Perhaps caution should be exercised in generalizing these results to include the clinical setting, because there is wide variation in fracture displacement as well as the relationship of fracture components to the axial and coronal planes for a given fracture type; for example, tripod zygomatic fractures. Not only does the intrinsic variegation of fracture geometry play a role, but there are variations in head position relative to the axial and coronal planes at the time of CT scanning. In addition, 1.5-mm sections were used in this experiment, requiring approximately 50–60 CT sections per scan orientation. In the clinical setting, and with most CT scanners in current use, the amount of time required to perform a high-resolution study such as reported here often is not tolerated. At present, alternative solutions include the use of thicker CT slices, for example, 3 mm, or fast scanning techniques. In light of the large radiation dose that would be encountered in a study with both 1.5-mm contiguous sections and double scanning angles, we anticipate that clinical investigation of the effect of CT scan orientation on the accuracy of 3-D reconstructions would be best served by initially modeling facial trauma in cadavers.

By using fractures created in a dried skull, we determined that certain nondisplaced fracture complexes appear better displayed in 3-D imaging by preselecting the axial or coronal plane. While the 3-D reconstruction algorithms differed between the two systems used in this experiment, it is suggested that our results are independent of the 3-D processing system used. It is anticipated that these observations can be used in planning the appropriate orientation for CT data acquisition in patients who have sustained severe facial trauma when 3-D CT reconstruction is planned as part of the preoperative evaluation.

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