Original Articles

Value of Three-Dimensional Computed Tomography in Craniomaxillofacial Surgery

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Three-dimensional (3-D) computed tomographic (CT) scans of 72 adult patients were evaluated by two observers in a blinded fashion by comparing the 3-D images with the two-dimensional (axial and coronal) CT scans. With 3-D CT, the observers found improved visualization of facial anatomy in certain patients (i.e., asymmetries of the whole face and skull, large defects of the midface and skull vault, and fractures with major dislocation). In these defects, the information can be assimilated more rapidly. The documentation of effects of cranial surgery on craniofacial growth and resorption after reconstruction with autologous material can also be evaluated more accurately. Because higher levels of radiation are used, 3-D CT protocols are less indicated in patients with minor dislocation of fractures, tumors, and inflammations. Three-dimensional CT images in these patients are of little help and can mislead the surgeon. Further improvements in hardware and software will allow more accurate surgical planning by performing interactive surgery or by producing precise models.

Key Words: Three-dimensional computed tomography, maxillofacial surgery

Progress in computer technology enabled the realization of three-dimensional (3-D) images reconstructed from two-dimensional (2-D) computed tomographic (CT) scans [1–3].

Several reports on 3-D CT reconstructions of the head and neck have been published [4–14] without offering a quality of the 3-D images that significantly surpasses the information provided by 2-D CT scans. Thus, until 1992, 3-D reconstruction was seldom required in the Department of Cranio-Maxillo-Facial Surgery of the University Hospital in Zurich. However, recent improvements in hardware and software allow 3-D images to be reformatted, giving decidedly more information with less radiation exposure because of shorter scan times.

This investigation was designed to analyze the value of recent 3-D images in contrast to axial and direct coronal scans in adult patients before and after craniomaxillofacial surgery. Other authors have studied some of the craniofacial defects described here [15–19].

Materials and Methods

Over a 12-month period (June 1992–May 1993) 72 adult patients (43 male, 29 female; age range = 18–69 years) were examined prospectively using high-resolution CT (HiQ-S, Siemens Medical Systems, Erlangen, Germany) on the basis of a specially designed protocol to enable 3-D reconstructions. CT examinations were carried out according to the same protocol and consisted of an average of 30 contiguous slices (slice thickness = 2 mm, table increment = 2 mm, 133 kV, 175 mA, scan cycle 2.7 s, resulting in a dosage of 472.5 mA per slice). The standard mode scanning in axial plane served as the basis for system-provided 3-D reconstructions (Somaris, Siemens Medical Systems), and raw data preservation in axial/coronal plane scanning was used for secondary high-resolution bone algorithm depiction of individual slices.

In patients with midface defects, slices were oriented parallel to the hard palate and were extended to cover the orbital roof or skull vault when necessary. Slice orientation was parallel to the mandibular body and ascending ramus, respectively, to cover defects of the jaw.

Table 1 shows the topographical regions of patients examined by CT. Nine patients had an examination of the entire skull, and 19 others had an examination of the entire viscerocranium (without supraorbital skull vault). The midface was reconstructed three dimensionally in an additional 20 patients without skull vault and without the mandible and was reconstructed with skull vault in 16.

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The presentations and panel discussion on pharyngoplasty led by Schprintzen emphasized the important role of speech pathologists in evaluating and establishing indications for secondary surgery. He also pointed out the problems associated with use of the pharyngeal flap as well as the causes of failure of this procedure.

The final session was devoted to skeletal surgery, with special attention paid to alveolar bone grafting, its timing, and technique. Various aspects and techniques of orthognathic surgery were very well presented by Kawamoto, Posnick, Ortiz-Monasterio, and Salyer. The vast majority of presenters and panel participants criticized primary bone grafting performed at 1 year of age and suggested age at mixed dentition to be a more reasonable and justifiable time to perform this procedure.

In summary, it should be emphasized that the symposium must be considered one of the most organized and scientifically most productive among many conferences devoted to this topic. On a final note, a research group on the topic was established so that their views and innovations could be exchanged in a collegial fashion.

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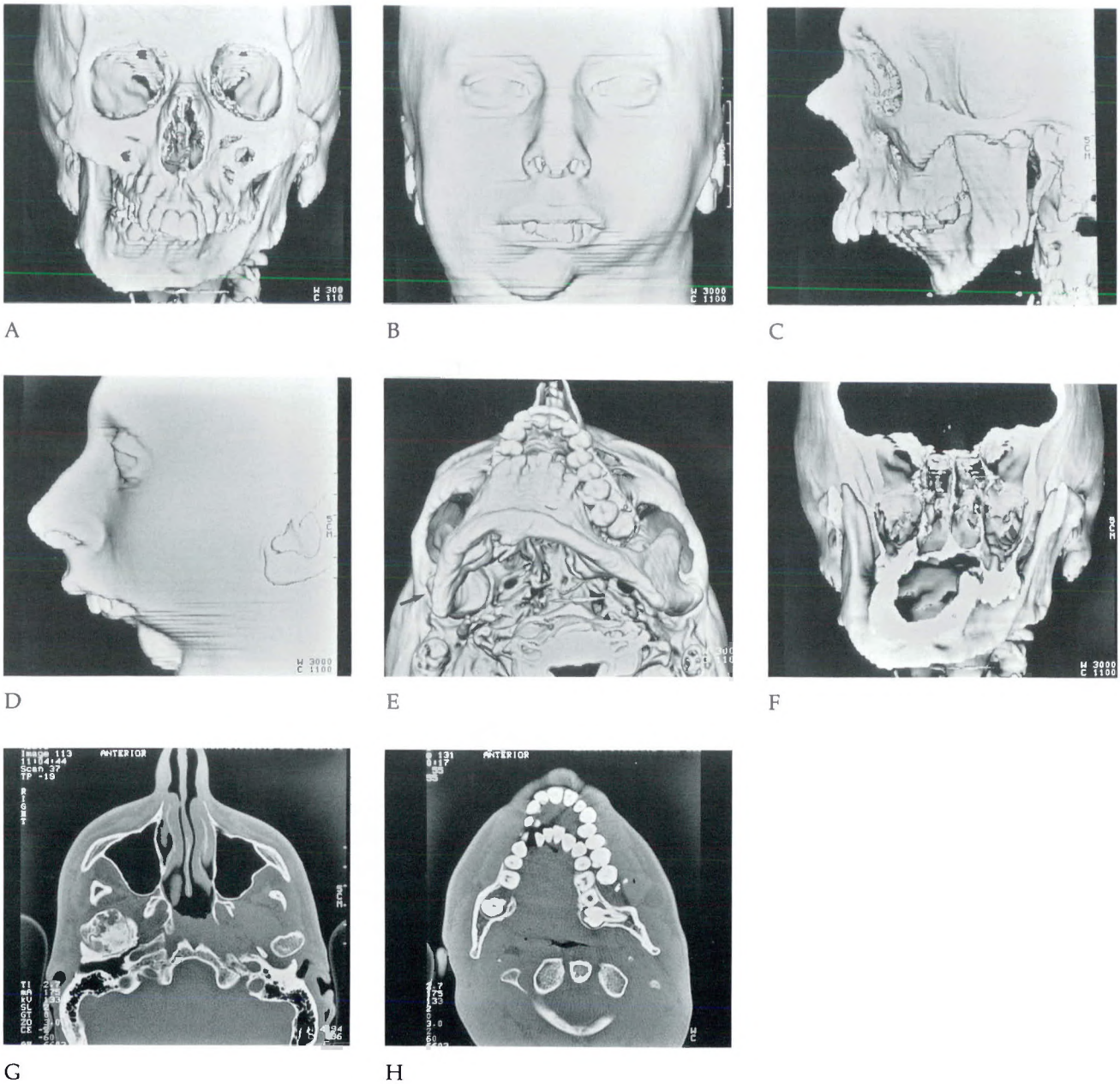


Fig 1 Major asymmetry of the entire face as a result of ankylosis of the right temporomandibular joint (TMJ) during childhood. (A) Frontal view of bony reconstruction. (B) Frontal view of surface soft tissues. Lateral views (C [bony reconstruction] and D [surface soft tissues]) show the massively retruded mandible. (E) Inferior view (indicator pointing toward the ankylosis of the involved TMJ). (F) Frontal view (a transanatomical "cut" in the frontal plane and taking away the anterior part shows relations between inner structures three dimensionally). (G) Axial computed tomographic (CT) scan showing ankylosis of the right TMJ more clearly. (H) Axial CT indicating lateralization of the mandible (see also Fig 1A, B, and E).

Table 1 Topographical Regions Investigated with Axial/Coronal Scans and Three-Dimensional Computed Tomography

Region	*Number*
Skull vault alone, including skull base	5
Entire skull (viscero- and neurocranium)	9
Entire midface and lower face, excluding skull vault	19
Midface, skull vault and mandible excluded	20
Midface, skull vault included, mandible excluded	16
Mandible alone	9

Table 2 Different Pathological Entities of Patients Examined with Computed Tomography

Defect/Disease	*Number*
Congenital malformations	21
Fractures	34
Tumors	12
Inflammatory disease	7
Degenerative disease	4

Skull vault and cranial base alone were investigated in 5 patients and the mandible alone in 9 patients.

The indications for performing CT scans were fractures of the skull (34 patients, of which 26 showed isolated fractures of the midface), congenital malformations (21 patients), tumors (12 patients), inflammatory diseases (7 patients), and degenerative diseases (4 patients) (Table 2).

Images were independently analyzed by Carls and Schuknecht on the basis of a scoring system (Table 3) described by Gillespie and colleagues [20]. Starting with the 3-D images available in multiple projections on hard copy, the information gained was scored and compared with the individual axial and coronal slices in standard and high-resolution bone algorithm. Intra- and interindividual results obtained for different topographical regions in combination with different pathologic entities are listed in Table 4.

Results

The results are summarized in Table 4. The highest score (additional information provided by 3-D reconstruction) was found in asymmetries of the entire skull. This entity consisted of acquired asymmetries (e.g., ankylosis of the temporomandibular joint developed during childhood or comminuted fractures of the midface, which are consolidated with major dislocation), as well as congenital malformations (e.g., Apert's syndrome, Crouzon's disease, hemifacial microsomia, and facial clefts).

Because of the large extension in different planes, not only were these asymmetries assimilated more rapidly, but additional information led to better evaluation in 3-D CT. In particular, the possibility to evaluate from different perspectives by rotating the 3-D delineated skull in different planes (Fig 1A, C, E) provided decisively more information than axial and coronal 2-D scans. Secondary cut options of the used software also provided 3-D images of inner structures, which added more information (e.g., the relation of jaws to the intraoral space; Fig 1F).

Defects of the skull vault were also more rapidly assimilated in 3-D reconstructions (score = 3). At times, additional information was provided (score = 4) (e.g., in cases of existing bone fragments within the defect; Fig 2).

Some patients showed such large defects of the midface (Fig 3) after tumor resection or gunshot wounds that they were categorized as a special group (defects of the midface in Table 4). This differentiated them from patients with smaller defects of the midface, because scoring of the latter was significantly lower in 3-D reconstructions.

Table 3 Scoring System (According to Gillespie and Colleagues [20])*

Score	*Description*
1	Inferior
2	Similar/equivalent
3	Superior (similar information more rapidly assimilated)
4	Superior (additional information provided)

*Three-dimensional reconstructions in comparison to coronal and axial computed tomographic scans.

Table 4 Value of Three-Dimensional Computed Tomography in Different Entities (Examined Region Combined with Disease/Defect and Diagnosis)

Entity	*Number of Patients*	*Scores*	*Average*
Dysplasias/asymmetries of the skull	14	4,3,4,4,4,4,4, 4,3,4,4,3,4,4	3.79
Defects of the skull vault	10	4,3,4,4,3,3,3, 4,3,4	3.50
Defects of the midface	6	3,4,4,2,3,4	3.33
Fractures of the midface			
With major dislocation	11	4,3,3,1,3,4,4,3, 2,4,4	3.18
Comminuted	8	2,2,3,3,1,2,3,2	2.25
Tripoid	7	2,3,2,1,2,1,2	1.86
Defects of the mandible			
Fractures	4	2,1,3,2	2.00
Reconstructions	3	3,2,2	2.33
Temporomandibular joint ankylosis/arthrosis	7	1,2,2,2,2,2,1	1.71
Inflammatory diseases	2	2,1	1.50
Tumors, cysts	6	1,1,2,2,3,2	1.83

Fractures of the midface were scored differently. Fractures with minor dislocation are less visible in 3-D CT because of computing procedures that eliminated artifacts and yielded smooth contours. In fact, fractures in 4 patients after midface trauma were incompletely diagnosed (score = 1) in 3-D CT scan. The more dislocation present, the more information the 3-D reconstruction provided. Reconstruction of 3-D images is a helpful tool in comminuted fractures with large dislocations. However, for fractures of thin bones (e.g., floor and roof of the orbit), it is currently not very helpful.

The different defects of the mandible alone (defect of the mandible and temporomandibular joint ankylosis/arthrosis in Table 4) were often not better investigated in 3-D CT. Exceptions include one isolated comminuted fracture of the mandible (10 pieces) and one difficult reconstruction of the mandible. Isolated major asymmetries of the mandible were not found because the midface was always involved as well, and these patients were thus grouped together with skull dysplasias/asymmetries in Table 4.

In only one of the patients with tumors or osteomyelitis was the extension such that 3-D delineation provided information more rapidly. 3-D CT scans of most other patients in these two groups were inferior to 2-D CT scans. Tumor margins and bone erosions were better visualized in the original slices because of the lower spatial resolution in the third dimension in 3-D CT (Fig 4).

Discussion

Ten years have passed since the promising delineation of the first 3-D reconstructions of 2-D CT scans of the skull [1–3]. Recently, a significant increase in quality was achieved [15,21–24]. These authors reported general progress in 3-D CT technique but provided little information on comparison and scoring between 3-D and 2-D images. Reports comparing part of the head and neck defect/disease were undertaken earlier [16,18,19]. In these reports, the authors compared and scored a subdivision of pathological diagnoses (craniofacial malformations, tumors, and fractures). Generally, this system would be desirable, but we currently consider it not applicable, even with today's improved quality of 3-D reconstructions. If the material in this study was subdivided into pure diagnostic entities, it should have scored the same diagnostic entities with very different scoring levels in 3-D CT scans. Fractures of the midface would be scored from 1 to 4 depending on the extent of the dislocation, whereas defects of the midface (representing the same topographical area) are almost always scored high (score = 3 and 4) in 3-D reconstructions. On the other hand, 3-D CT is of little use in tumors of the midface (again the same topographical area) because details of inner structures and the very important borderlines are often not adequately visualized in 3-D CT (see Fig 4).

Ankylosis of the temporomandibular joint can lead to excessive asymmetry of the whole face (see Fig 1) and the 3-D images are very helpful. In contrast, the ankylosis itself (see indicator in Fig 1E) is much better visualized in a 2-D scan (see Fig 1G). For these reasons, we chose the subdivision presented in Table 4, combining topographical areas with pathological entities.

This subdivision shows that the value of 3-D reconstructions of CT scans is best in asymmetries of the whole face and that no differences are found between acquired asymmetries resulting from trauma or tumor resection and congenital malformations [12,24]. The evaluation of asymmetries in smaller facial areas is also good in 3-D CT but requires conventional x-ray films and is more time consuming [25].

We also found 3-D reconstructions to be extremely valuable in defects of the skull vault because the extent of these defects was more rapidly assimilated (score = 3). The 3-D CT was especially valuable when the defect was located in topographical areas where conventional x-ray films are of little help, when larger defects showed bony fragments (Fig 2C, D, E), and when evaluation of growth and resorption was requested [26]. On the contrary, less information is gained in deformities of the skull such as simple craniosynostosis when compared to conventional x-ray films [24,26]. Therefore, examination of the skull vault in contiguous slices for 3-D reconstruction is most often not indicated considering the higher levels of irradiation [27].

In general, fractures, inflammations, and tumors of all topographical areas did not score high in 3-D CT reconstructions because axial and coronal planes provided much more information on details [15,24]. During intensive study of these 2-D CT scans, the investigator combines them mentally and imagines the third dimension,

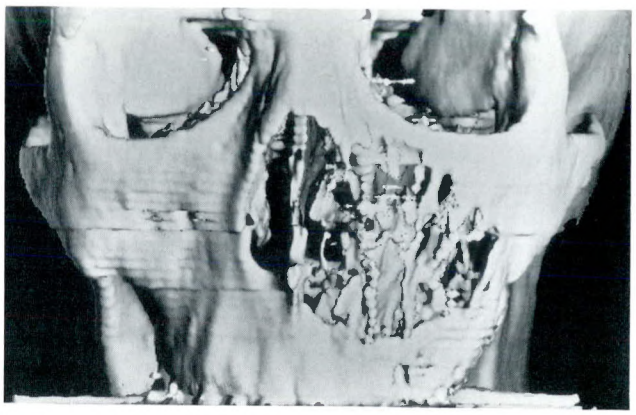
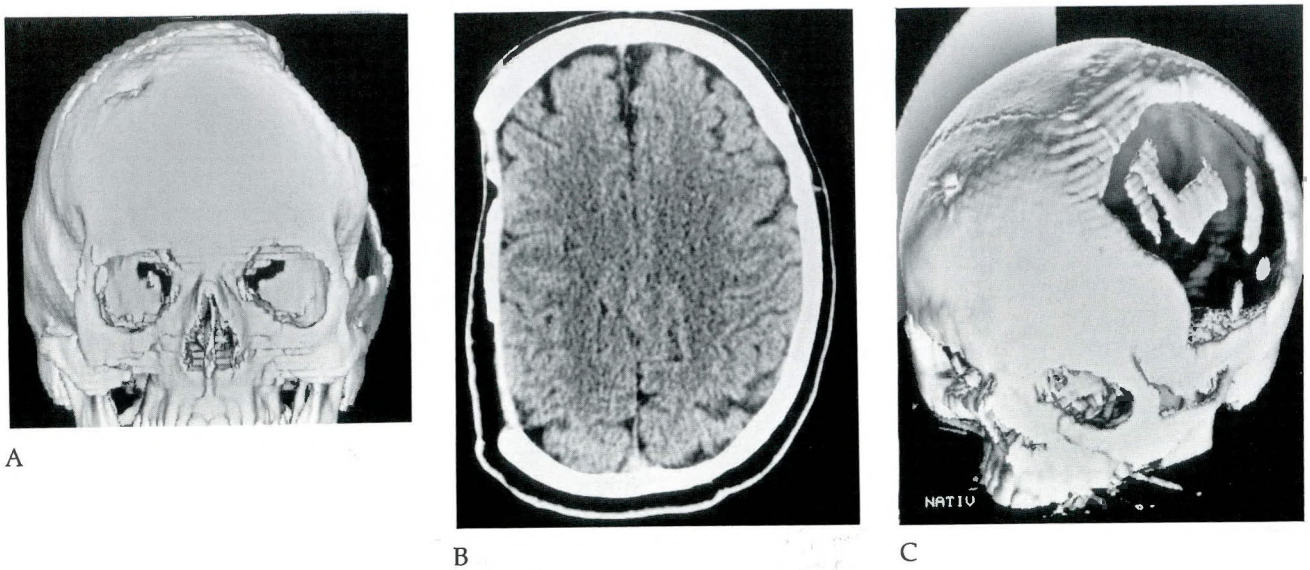
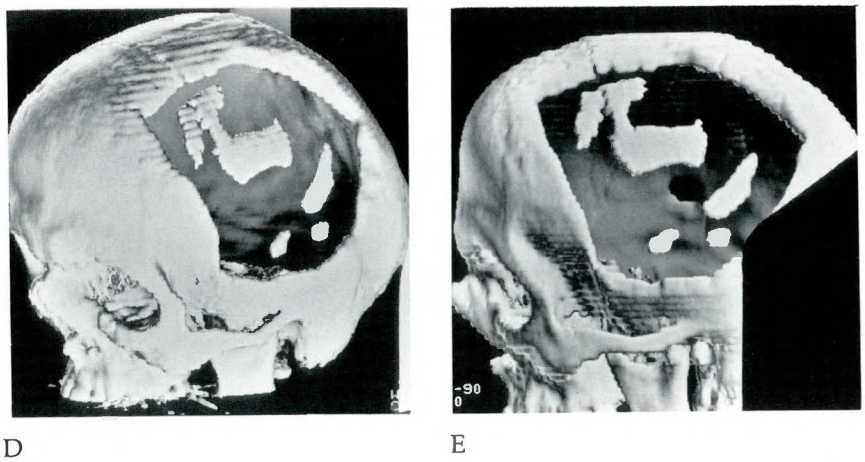


Fig 4 Large tumor in the left midface (myxoma).

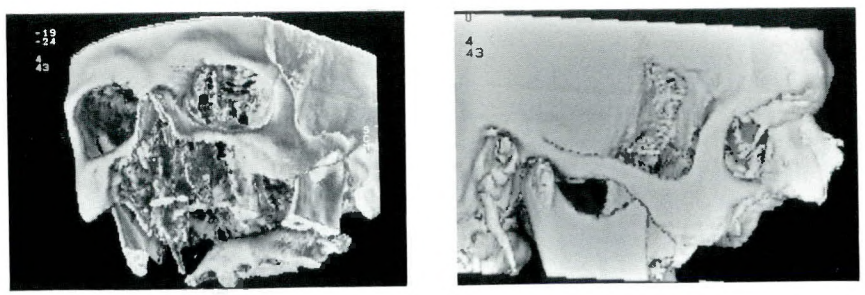


A B C



D E

Fig 2 Patient with large defect of the skull vault. (A) Frontal view showing part of the defect. (B) Axial scan showing part of bone fragments within the defect. (C–E) Three-dimensional computed tomographic scan delineating defect and bony fragments more rapidly (score = 3).



A B

Fig 3 Large defect of the midface after gunshot wound (A) Oblique view. (B) Lateral view.

possible largely because of the surgeon's knowledge of the skull from everyday surgical work. In this way, the 3-D evaluation during x-ray study is more time consuming but represents a by-product of the mandatory study of axial and coronal planes.

Almost all other authors [15,16,24,28,29] reported that thin structures (e.g., orbital floor, lamina papyracea) are not yet well visualized in 3-D CT because of artificial defects/pseudoforamina, even in thin 2-mm slices as a result of the partial volume effect. Future software and further reduction of slice thickness will continue to improve the image quality of these structures. Image clarity in the scans of our patients was not reduced by scatters of plate and screw fixation because titanium implants were used, which often do not interfere with 3-D CT [30].

This study was undertaken only in adults with the same examination protocol because children are examined in the children's hospital with a different CT scanner using another examination protocol. Therefore, the 3-D reconstructions cannot be compared in the same scoring system. Kreiborg and associates [22] studied the important role of 3-D CT in children with Apert's syndrome and Crouzon's disease.

Further improvements in computer software will allow more precise planning of craniofacial operations by performing interactive surgery on the computer screen [21,21a] or by producing precise skull models [31–34]. Thus, the value of 3-D CT in craniomaxillofacial surgery will further increase.

Conclusion

In certain patients, 3-D CT scans improve the visualization of facial anatomy. Such patients have asymmetries of the whole face, large defects of the midface and skull vault, as well as fractures with major dislocation. In these defects, greater amounts of information can be assimilated more rapidly. In patients with minor dislocation of fractures, tumors, and inflammations, 3-D CT protocols are less indicated. The documentation of effects of cranial surgery on craniofacial growth and resorption after reconstruction with autologous material can be evaluated more accurately.

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