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Use of intraoperative computed tomography for maxillofacial reconstructive surgery.

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Journal

JAMA facial plastic surgery, 17(2)

ISSN

2168-6076

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Publication Date

2015-03-01

DOI

10.1001/jamafacial.2014.1343

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Peer reviewed

Original Investigation

Use of Intraoperative Computed Tomography for Maxillofacial Reconstructive Surgery

David A. Shaye, MD; Travis T. Tollefson, MD, MPH; E. Bradley Strong, MD

IMPORTANCE Intraoperative computed tomography (CT) provides surgeons with real-time feedback during maxillofacial trauma and reconstructive surgery, which can affect intraoperative decision making.

OBJECTIVES To evaluate the time needed to perform intraoperative CT scans during maxillofacial surgery, determine any trend toward shorter total scan times as experience is gained with the technique, and identify the characteristics of cases that required intraoperative revision based on the results of intraoperative CT scanning.

DESIGN, SETTING, AND PARTICIPANTS A retrospective review was completed for all maxillofacial reconstruction procedures that used intraoperative CT between January 1, 2012, and March 31, 2014.

INTERVENTIONS Patients were cared for by the routine practice pattern of the authors. Intraoperative CT scans were obtained for all patients.

MAIN OUTCOMES AND MEASURES Time needed for intraoperative CT scan was measured and trends were analyzed. Covariates included age, sex, complexity of fracture, procedure type, total scan time, surgeon, and need for intraoperative revision based on intraoperative CT findings.

RESULTS Thirty-eight cases were identified, including 30 males (79%) and 8 females (21%). The mean (SE) age was 37.4 (16.0) years (range, 7-75 years). Cases were defined as routine (18 [47%]) or complex (20 [53%]). Isolated orbital fractures were the most common fracture (23 [61%]) in both the routine (14 [78%]) and complex (9 [45%]) cases. The mean (SE) total scan time was 14.5 (4.9) minutes (range, 6-27 minutes) and did not differ based on complexity ($P = .34$). Intraoperative revisions were performed in 9 patients (24%) and were more common in complex ($n = 8$) than routine ($n = 1$) cases ($P = .004$). There was no reduction in total scan time during the study period ($P = .22$). The mean (SE) scan time for the most experienced surgeon was 3.78 (1.53) minutes shorter than for the other surgeons as a group ($P = .02$).

CONCLUSIONS AND RELEVANCE Current intraoperative CT scanning techniques are rapid, averaging 14.5 minutes per case. No decrease in total scan time was noted during the study; however, the surgeon most experienced with the CT software had the shortest total scan times. Intraoperative revisions were most common in complex cases. We recommend surgeons consider the use of intraoperative CT imaging for maxillofacial reconstruction, particularly in complex procedures.

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JAMA Facial Plast Surg. doi:10.1001/jamafacial.2014.1343
Published online January 8, 2015.

Intraoperative imaging plays an integral role in orthopedic surgery during repair of long-bone fractures. It provides real-time feedback and the ability to perform intraoperative revisions for malreduction or malpositioning of implants. Given the complexity of the facial skeleton, intraoperative imaging has the potential for similar benefits in maxillofacial reconstruction. The sensitivity, specificity, and resolution of computed tomography (CT) are superior to either plain or panorex radiographs.¹⁻³ Computed tomography has therefore become the gold standard for the diagnosis and treatment of maxillofacial injuries. Disadvantages of intraoperative imaging include the expense and availability of the scanner, concerns about excessive radiation exposure, increased operative times, and lack of controlled prospective outcome studies evaluating the use of intraoperative CT.

The advent of portable CT scanners spurred surgeons to investigate intraoperative imaging.^{4,5} While these studies concluded that intraoperative CT was a viable technique, the early portable scanners were limited in number, cumbersome to use, and had rudimentary segmentation and volume-rendering capabilities. As a result, intraoperative CT scanning was rarely used. Current portable CT scanners have a much smaller footprint, greater maneuverability, marked improvement in image resolution, and a significant reduction in radiation exposure. Consequently, portable CT scanners are becoming more common in intensive care units, emergency departments, and operating rooms.

Computed tomography scanners can be divided into 2 different modalities: traditional computed axial tomography (also called *fan beam* CT) and digital volume tomography (also called *cone beam* CT). Fan beam scanners use a collimator to generate a fan-shaped beam, providing “slices” that can be evaluated in 2 dimensions or combined to generate a 3-dimensional volume. Cone beam scanners differ in that they emit a cone-shaped x-ray beam that is recorded as a 3-dimensional volume. This volume can then be sliced into 2-dimensional images in virtually any plane. A comparison of the 2 techniques reveals that fan beam CT provides the greatest image resolution, while cone beam CT offers a significant reduction in radiation exposure. This reduction results in more limited soft-tissue resolution but maintains adequate bone resolution for intraoperative decision making.

Radiation exposure is central to any risk-benefit decision regarding the use of intraoperative imaging for maxillofacial surgery. Studies have tried to examine the long-term risk of medical radiation exposure and, more specifically, CT imaging.⁶⁻⁸ The longitudinal nature of such studies makes them difficult to interpret for any patient. Radiation dosage for a maxillofacial fan beam CT scan is approximately 600 to 800 μ Sv and for a cone beam CT scan is approximately 40 to 80 μ Sv. Relative radiation doses from other common sources include mammogram, 400 μ Sv; 2-view chest radiograph, 100 μ Sv; and daily background radiation, 8 μ Sv every 24 hours (Table 1).⁹

The application of intraoperative imaging for maxillofacial surgery has evolved during the past 15 years. In 1999, Stanley⁴ used intraoperative CT for evaluation of 25 orbito-zygomatic fractures, 7 (28%) of which were revised based on intraoperative CT findings. He concluded that CT was helpful

Table 1. Relative Radiation Doses of Various Radiography Techniques⁹

Radiographic Imaging	Radiation Dose, μ Sv
Maxillofacial	
Fan beam CT	600-800
Cone beam CT	40-80
Mammogram	400
2-View chest radiograph	100
Daily background radiation	8

Abbreviation: CT, computed tomography.

for corrections in malar eminence discrepancies and provided a reference for orbital wall repairs. Hoelzle et al⁵ reviewed 29 orbito-zygomatic fractures and also concluded that intraoperative CT was beneficial. Four of their 29 patients (14%) underwent intraoperative revision after open reduction internal fixation, and 3 underwent closed reduction, with intraoperative CT being the only fracture visualization technique used. Stuck et al¹⁰ reviewed 46 consecutive patients with a facial fracture using intraoperative CT and found a 26% intraoperative revision rate. These revisions included 5 patients with malreductions, 5 patients with implant malpositions, and 2 patients who required removal of bone fragments.

The objectives of this study were to evaluate the time needed to perform intraoperative CT scans during maxillofacial reconstruction, determine if a trend toward shorter total scan times is noted as experience is gained with the technique, and identify the characteristics of cases that required intraoperative revision based on the results of the intraoperative CT scan.

Methods

After University of California–Davis Institutional Review Board approval, we performed a retrospective review of all maxillofacial trauma and reconstructive procedures using intraoperative imaging between January 1, 2012, and March 31, 2014. Covariates included age, sex, fracture complexity, procedure type, total scan time, and need for intraoperative revision based on CT findings. Total scan time was recorded as the time (in minutes) from when the surgery ceased (to start the scanning process) until the time the surgeons resumed the procedure. The total scan time included the time for patient draping, positioning in the scanner, scan acquisition, data processing, and data interpretation. Fracture complexity was defined as either *routine*, when fractures were limited to 1 area of the facial skeleton (eg, orbit, zygoma, or simple zygomaticomaxillary complex fractures), or *complex*, when more than 1 area was involved (eg, Le Fort fracture, naso-orbital-ethmoid fracture, or orbital fractures involving ≥ 2 walls). Any secondary revision procedure or delayed repair was considered complex.

Intraoperative Scanning Protocol

Radiology department technicians were notified of the procedure the morning of surgery. An operating room with adequate size for the equipment was chosen, and the patient's

Figure 1. Preparation for Intraoperative Imaging

The patient is draped and aligned with the intraoperative computed tomography scanner in the operating room.

head was oriented toward the door for easy access to the scanner. A radio-opaque headrest was applied to the bed prior to the patient entering the room. The use of metal instruments (eg, towel clips) within the surgical field was avoided to minimize x-ray scatter. Thirty minutes prior to the CT scan, the radiology department was contacted to warm up and transport the scanner to sit just outside the operating room. To acquire the scan, a sterile C-arm drape was placed over the patient, and the scanner was positioned over the patient (Figure 1). Non-critical personnel left the room while essential personnel remaining in the room used a lead shield. The scan was acquired. While the scan was being formatted and reviewed, the scanner and C-arm drape were removed in preparation for wound closure or any intraoperative revision that may be required based on the scan results.

Statistical Analysis

Univariate analyses were conducted for all continuous variables to examine measures of central tendency using *t* tests, and χ^2 or Fisher exact tests were used for categorical variables. The *t* test was used to test the null hypothesis that there would be no difference in mean scan times for complex cases compared with simple cases. The *t* test was also used to test a second null hypothesis (mean scan times were not different between individual surgeons). Two linear regression models were used. One tested for a time trend in CT total scan time (in minutes). The dependent variable was time needed for intraoperative CT scan, and the independent variable was the day of surgery during the study. A second linear regression model was used to test for a trend in scan times between surgeon 1 (most experienced) and surgeons 2 through 5. Analyses were conducted in R, version 2.13.0 (R Development Core Team). $P < .05$ was considered statistically significant.

Results

Overview

Thirty-eight maxillofacial reconstruction cases were included in the analysis (Table 2). Mean (SE) patient age was

37.4 (16.0) years (range, 7-75 years), including 30 males (79%) and 8 females (21%). Cases were defined as routine (18 [47%]) or complex (20 [53%]). Diagnosis and applicable procedures included are shown in Table 2. Isolated orbital fractures were most common (23 [61%]) in both the routine (14 [78%]) and complex (9 [45%]) cases.

Scan Time Analysis

The mean (SE) total scan time was 14.5 (4.9) minutes (median, 13 minutes; range, 6-27 minutes) and did not differ between simple and complex cases ($P = .34$). The mean total scan times by individual surgeon are shown as boxplots in Figure 2. Note one outlying data point in surgeon 1's boxplot (23 minutes), which occurred in the last 2 months of the study period (see the Discussion section).

Linear Regression Results

A linear regression model was fitted to test the hypothesis that total scan times would decrease in the later months of the study, which lasted for more than 2 years. The total scan time did not significantly change during the study period from 2012 to 2014 ($P = .22$) (Figure 3).

The second linear regression model was fitted to test specifically for differences between the surgeon most experienced with intraoperative CT (surgeon 1) and surgeons 2 through 5. It revealed that the mean (SE) total scan time for surgeon 1 was 3.78 (1.53) minutes shorter than for the other surgeons as a group ($P = .02$) (Figure 4). This outcome was verified with and without adjusting for day of study since this covariate was not significant ($P = .34$) and demonstrated a small effect.

Intraoperative Revision

Intraoperative revisions were performed in 9 patients (24% of the total cases). Revisions were more common in complex ($n = 8$) than routine ($n = 1$; 1-wall orbital fracture) cases ($P = .004$). Of the complex cases, nearly half (8 of 20 [40%]) underwent intraoperative revisions including 5 orbital reconstructions, 1 panfacial (Le Fort/naso-orbital-ethmoid) fracture, 2 orbito-zygomatic fractures, and 1 orbito-zygomatic tumor reconstruction. Three of the 9 patients who had an intraoperative revision also underwent repeat intraoperative scanning to confirm final placement of the implant. Two of these 3 patients were undergoing complex, secondary orbital reconstructions.

Discussion

Scan Time

Historically, intraoperative CT scanners were cumbersome, time consuming, costly, and resulted in significant radiation dosage to the patient. Newer portable CT scanners are extremely mobile and have 1- to 2-minute scan times, rapid processing algorithms for data presentation, and low radiation dosage. Consequently, the average additional operative time for intraoperative CT scan acquisition in this study was 14.5 minutes.

Table 2. Baseline Characteristics by Complexity of Fracture^a

Characteristic	No. (%) ^b			P Value ^c
	All Cases	Routine	Complex	
Patients	38 (100)	18 (47)	20 (53)	
Sex				
Male	30 (79)	13 (72)	17 (85)	.13
Female	8 (21)	5 (28)	3 (15)	
Age, y				
Mean (SE)	37.4 (16)	37.3 (12)	37.6 (20)	.95
Median (range)	36 (7-75)	37 (15-57)	35 (7-75)	
Procedure				
Isolated orbital	23 (61)	14 (78)	9 (45)	.01
Isolated zygoma	2 (5)	2 (11)	0	
ZMC/orbital	5 (13)	2 (11)	3 (15)	
Le Fort/NOE	4 (11)	0	4 (20)	
Mandible	1 (3)	0	1 (5)	
Orbit roof (tumor)	3 (8)	0	3 (15)	
Surgeon				
1	24 (63)	8 (21)	16 (42)	.009
2	9 (24)	6 (16)	3 (8)	
3	2 (5)	2 (5)	0	
4	2 (5)	2 (5)	0	
5	1 (3)	0	1 (3)	
All surgeons	38 (100)	18 (47)	20 (53)	
Scan Time, min				
First scan (n = 38)				
Mean (SE)	14.5 (4.9)	13.7 (5.0)	15.2 (4.7)	.34
Median (range)	13.0 (6-27)	13.5 (6-27)	13.0 (9-26)	
Second scan (n = 3)	9.7	10.0	9.5	
Modification				
Yes	9 (24)	1 (6)	8 (40)	.004
No	29 (76)	17 (94)	12 (60)	

Abbreviations: NOE, naso-orbito-ethmoid fracture; ZMC, zygomaticomaxillary complex.

^a Complexity of case was defined as *routine* when fractures were limited to 1 area of the facial skeleton (eg, orbit, zygoma, or simple ZMC fractures) or *complex* when more than 1 area was involved (Le Fort, NOE, or orbital fractures involving 2 or more walls), any revision case, and secondary traumatic deformities.

^b Percentages may not total 100% due to rounding.

^c P values were calculated using a χ^2 test or Fisher exact test for discrete variables and a t test for continuous variables.

The total scan time can be broken into 5 phases.

1. Patient draping: A C-arm drape is passed over the patient's head to avoid contamination from the scanner. While the scanner itself can be draped, we have found the use of a C-arm drape over the patient to be most efficient.
2. Scanner positioning: The scanner must be positioned over the patient in orthogonal planes and encompass the anatomical area of interest. Many scanners have used a scout film or a positioning beam to achieve these goals.
3. Scan acquisition: This is generally a rapid automated process performed by a radiology technician.
4. Data processing: After acquisition, the technician must format and process the data into axial, coronal, sagittal, and 3-dimensional representations. The time necessary for data processing is highly dependent on technician training and experience with the individual scanner software and protocols.
5. Scan interpretation: The surgeon must evaluate the scan and make a decision if further intervention is necessary.

Efficient intraoperative CT scanning requires coordination between the surgeon, operating room staff, and radiology technicians. We have found that establishment of repeatable workflows and thorough training of support staff will

significantly reduce total scan times. Some highlights include thorough radiology technician training, early contact with the radiology department to inform them of the procedure time and location, reservation of an appropriate-size room with a radiolucent bed/head-holder, timely contact with the radiology technician approximately 30 minutes prior to the scan to allow for transport of the scanner, prepositioning of the scanner while the patient is being draped, and removal of the drapes and reexposure of the operative field while data processing and interpretation are being performed. Creating redundancy in the system by cross-training surgeons, operating room staff, nurses, and radiology technicians on the workflow can be effective in process improvement.

An approximate breakdown of the total scan time is listed below.

1. Patient preparation: 1 to 2 minutes to apply the C-arm drape.
2. Scanner positioning: 2 to 4 minutes to position the patient in the gantry.
3. Scan acquisition: 1 to 2 minutes to obtain the scan.
4. Data processing: 3 to 10 minutes for the technician to process the data.
5. Scan interpretation: 1 to 3 minutes for the surgeon to analyze the data.

Of the total scan time, the surgeon's role (patient preparation and scan interpretation) is quite brief. There is little room for improved efficiency; however, the technician's role (scanner positioning and data processing) is the most time consuming and has the greatest potential for improved efficiency. During the study, we noted that cases performed by experienced technicians had the shortest total scan times, while those performed by inexperienced technicians had the longest total scan times. While this finding is anecdotal, there are several findings that support this hypothesis. First is the outlying 23-minute scan recorded by surgeon 1 within

Figure 2. Intraoperative Scan Times by Surgeon

Intraoperative computed tomographic scan time by surgeon. Times were not significantly different (total mean [SE] scan time, 14.5 [4.9] minutes; median, 13 minutes; and range, 6-27 minutes; $P = .34$). Surgeon 1 completed 24 (63%) and surgeon 2 completed 9 (24%) of all the cases. Note 1 outlier in surgeon 1's boxplot (23 minutes). The dashed vertical lines represent the minimum and maximum of the scan time for each surgery. The solid horizontal lines indicate the interquartile range (25%-75%); the central horizontal line represents the median.

Figure 3. Linear Regression Model of Intraoperative Computed Tomographic Scan Time by Day of Study

The best line fit (horizontal line) shows a positive slope, but the slope is not significant ($P = .22$).

the last 2 months of the study period (Figure 2). During this specific procedure, the primary surgeon was summoned urgently from the case during the scanning process. On returning to the operating room, the primary surgeon found that an inexperienced technician was struggling with the scanner software used to process the data. This significantly extended the data processing portion of the total scan time. While the scan times for this study were not recorded by phase (eg, patient preparation, patient positioning, or scan acquisition), the prolonged length of this particular scan was clearly the result of inefficient data processing. A second finding, which supports the stated hypothesis, is the observation of shorter total scan times for surgeon 1 (Figure 4). Surgeon 1 had the most experience with the scanner and had received training on the use of the processing software. Consequently, surgeon 1 routinely helped the more inexperienced technicians with both patient positioning and data processing. This fact may explain the 3.78-minute reduction in total scan time for surgeon 1.

Characteristics of Intraoperative Revision Procedures

The results of this study are consistent with those of previous reports^{4,5} that suggest intraoperative CT can accurately detect bone or implant malposition. Immediate identification allows for correction at the time of initial repair and averts the need for a secondary procedure. In the current study, 9 of 38 patients (24%) underwent an intraoperative revision based on the CT scan findings. It is safe to assume that a surgeon's threshold for revising a procedure will be significantly lower if an error is noted intraoperatively as opposed to postoperatively. To determine which (if any) of the 9 patients who underwent intraoperative revision would have ultimately gone on to a revision at a secondary setting is beyond the scope of this study. However, given the complexity, cost, and risk of secondary revision maxillofacial

Figure 4. Scan Time by Surgeon Experience

Scatterplot of the scan time (in minutes) by dichotomized surgeon groups (1 indicates most experienced surgeon with intraoperative computed tomography scanner, and 2, other 4 surgeons). The linear regression model demonstrates that mean (SE) scan time for the most experienced surgeon was 3.78 (1.53) minutes shorter than for other surgeons ($P = .02$).

procedures, it would take very few secondary revision procedures to justify the use of intraoperative imaging.

Procedures included in the study were broadly classified as either routine or complex based on fracture severity, delayed nature of the injury, and area of the facial skeleton. The vast majority of patients who underwent an intraoperative revision had complex injuries. Two of these patients (both with complex orbital reconstructions) also underwent a second intraoperative CT scan to confirm the final placement of the implant. In our opinion, the decision to repeat an intraoperative scan is not necessary in all patients. The potential risk of radiation exposure with a repeat CT scan (particularly in pedi-

atric patients) must be weighed against the risk of a persistent malreduction or implant malpositioning. While the use of intraoperative surgical navigation can be of assistance in this regard (and is commonly used by the authors), definitive information about a bony reduction or implant positioning is best obtained from CT imaging (case examples are shown in Figures 5, 6, and 7).

The complexity of a surgical procedure is not based only on the severity of the injury but also on a surgeon's experience and proficiency. While it would be challenging to study, it could be postulated that less-experienced surgeons would benefit more from the use of intraoperative imaging while

Figure 5. Intraoperative Computed Tomographic Image of a Reduced Zygomatic Arch Fracture

Intraoperative computed tomographic images of treated facial fractures. A, Preoperative. B, Postreduction.

Figure 6. Intraoperative Computed Tomographic Image of a Complicated Mandible Fracture

A, Preoperative computed tomographic image of a complicated mandible fracture in a patient with upper facial skeleton fractures. B, Intraoperative computed tomographic scan confirming adequate reduction of mandible fracture prior to moving forward with open reduction internal fixation of upper facial skeleton fractures.

Figure 7. Intraoperative Computed Tomographic Image of an Orbital Floor Fracture and Implant

A, Preoperative orbital floor fracture. B, Intraoperative computed tomographic scan confirming proper position and contour of the implant.

more-experienced surgeons could be more selective in its use. The educational value of intraoperative imaging has been previously documented¹¹ and fulfills an educational objective by providing timely and specific feedback to both the trainee and primary surgeons. In the current landscape of work-hour restrictions and less resident continuity of care, the immediate feedback may be instrumental in shortening the learning curve for proficiency in maxillofacial reconstruction.¹²

This study had several limitations. This was a retrospective study, and patient selection may have been biased toward those with more complex or difficult injuries. The small sample size, lack of a control group, and lack of long-term follow-up do not allow for an assessment of patient outcomes.

Conclusions

Intraoperative CT is a valuable tool in the management of facial fractures and maxillofacial reconstruction. While these scans add approximately 14.5 minutes per case, they provide invaluable intraoperative information that can significantly lower the threshold for a surgical revision and potentially improve patient outcomes. Thorough radiology technician training and experience appears to reduce total scan time. We recommend surgeons consider the use of intraoperative CT imaging in maxillofacial reconstructive surgery, particularly in complex cases.

ARTICLE INFORMATION

Accepted for Publication: October 15, 2014.

Published Online: January 8, 2015.
doi:10.1001/jamafacial.2014.1343.

Author Contributions: Dr Shaye had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: All authors.

Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: All authors.

Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Shaye, Tollefson.

Administrative, technical, or material support: Shaye, Strong.

Study supervision: Shaye, Strong.

Conflict of Interest Disclosures: None reported.

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