Cost-Based Decision Analysis of Postreduction Imaging in the Management of Mandibular Fractures

Dane Michael Barrett, MD; Travis W. Halbert, BS; Caitlin E. Fiorillo, MD; Stephen S. Park, MD; J. Jared Christophel, MD, MPH

Importance
Immediate postreduction imaging is a standard practice in the management of mandibular fractures at many hospitals. However, the literature suggests that postreduction imaging in maxillofacial fractures fails to influence clinical decision making significantly.

Objectives
To determine the cost-effectiveness of different clinical decision pathways regarding postreduction imaging as it relates to the experience of the surgeon, and to demonstrate that baseline postreduction imaging has utility based on the complication rate of the surgeon.

Design, Setting, and Participants
We developed a decision tree model using commercially available software. The model accounted for cost of imaging modalities, adequacy of reduction, complication rate, cost of initial operating room time, and, if applicable, operative charges for revision surgery in the event of a complication. A review of the University of Virginia clinical data repository of 100 patients with recent mandible fractures was used to estimate the cost associated with running an operating suite for mandibular fracture repair. The University of Virginia billing system also provided costs associated with a single computed tomogram, panoramic radiography, and intraoperative 3-dimensional computed tomography. A sensitivity analysis determined how variation in complication rate affects the cost of the decision pathways.

Intervention
Intraoperative imaging, postreduction imaging, or no imaging.

Main Outcomes and Measures
Sensitivity of the decision tree model to variation in complication rate.

Results
Using current hospital charges, the model is sensitive to variability in the complication rate with a breakpoint of 17.7%. It is most cost-effective to obtain a post-reduction panorex if the surgeon’s complication rate is above 17.7% and most cost-effective not to obtain any postreduction imaging if the complication rate is below 17.7%. Intraoperative computed tomography is not cost-effective at any complication rate. Two-way sensitivity analysis allowed the model to be generalizable to varied institutional costs and surgical complication rates.

Conclusions and Relevance
The utility of postreduction imaging from the standpoint of cost analysis depends on the complication rate of the facial traumatologist and institutional charge data. Based on this model, the facial traumatologist at our institution should obtain postreduction panorex imaging for patients with mandible fractures until their complication rate drops below 17.7%. The 2-way sensitivity analysis in this study allows the facial traumatologist to apply his or her complication rate and institutional cost data to determine whether routine postreduction imaging is necessary.

Level of Evidence
NA.
Management of facial fractures places a considerable burden on the health care system. During 2007 alone, 407,167 visits to US emergency departments for facial fractures led to a total hospitalization time in the United States of 534,322 days.1 Mandibular fractures constitute 36% to 54% of all facial fractures and represent a significant portion of the financial burden due to facial trauma.2

With the ever increasing cost of health care, the development of practice patterns that efficiently and effectively result in a complication-free repair is paramount. Cost-effectiveness and the utility of different aspects regarding management of facial fractures have already been studied thoroughly in the literature. Past reports have compared the cost-effectiveness of different reduction and fixation techniques for facial fractures.3-6 Others have evaluated the utility of postoperative imaging, citing that routine postoperative radiography does not significantly influence clinical decision making in the treatment of maxillofacial trauma.2,7-11 Jain and Alexander,12 for example, concluded that intraoperative imaging, providing a baseline of the repaired fracture’s alignment and hardware positioning.9 Should a complication develop, a simple panorex radiograph can be obtained and compared with the baseline radiograph to guide further clinical decision making. A baseline study provides useful information in deciding whether a return trip to the operating room (OR) is necessary. If no postoperative baseline radiograph is available and a possible complication arises, the practitioner will often order more expensive computed tomography (CT) to provide useful information.

The other option would be the use of intraoperative CT to confirm radiologic alignment. This method does not require a separate operation should alignment be inadequate. However, intraoperative CT adds to operative time at the initial surgery. Overall treatment cost thus depends highly on the provider’s choice of imaging modality and complication rate. In the literature, complication rates requiring return to the OR at any time in the postoperative period range from 9% to 25%.13-18

Methods

A model decision tree was developed to mirror clinical decision-making pathways that are most often used to assess adequacy of fracture reduction (Figure 1). The model has the following 3 pathways for the surgeon: intraoperative CT, immediate postoperative panorex radiography, and no imaging. After choosing 1 of the 3 pathways, the model simulates the costs of clinical care from that point onward. Costs are set in US dollars. The possibility exists that the initial reduction is inadequate and must be immediately redone. Once the reduc-

Figure 1. Decision Tree Model

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Cost Components</th>
<th>Cost Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOCT</td>
<td>Cost of OR + Cost of IOCT + Cost of AORT + Cost of CT + Cost of COR</td>
<td></td>
</tr>
<tr>
<td>PR</td>
<td>Cost of OR + Cost of PR + Cost of OR + Cost of PR + Cost of COR</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>Cost of OR + Cost of CT + Cost of OR + Cost of PR + Cost of COR</td>
<td></td>
</tr>
</tbody>
</table>

0.99 indicates the proportion of the time that the reduction is adequate immediately after surgery (ie, no immediate realignment if using intraoperative computed tomography [IOCT] and no immediate return to the operating room [OR] after postoperative panorex radiography [PR]).9 The complication rate (CR) + 0.01 is the aforementioned proportion plus 0.01 because no intervention (IOCT or postoperative PR) was performed and assuming that no immediate return to OR occurs in this setting. AORT indicates cost of additional OR time; COR, cost of OR.
tion is adequate, a postoperative complication may occur in the future. Postoperative complication was defined as the need to return to the OR for any reason. The need for further imaging and further OR costs subsequently emerge as possibilities. After the initial decision node (1 of 3 pathways), the model encounters chance nodes where variables, such as chance of adequate reduction and chance of complication, determine the proportion of cases that follow different pathways. Costs are then incurred based on the operation and imaging choice.

The study was approved by the University of Virginia Institutional Review Board for Health Sciences Research (HSR# 16217). The variables for the model were obtained from the literature where available. Cost data were obtained from the University of Virginia clinical data repository (Table). A clinical data repository review of 100 recent deidentified patients treated for mandible fracture was used to estimate the charges associated with running an operating suite for mandibular fracture repair. The mean charge of a return to the OR for a complication was determined from the 6 most recent patient complications. The University of Virginia billing system also provided costs associated with single CT, panorex radiography, and intraoperative 3-dimensional CT. Finally, we performed a sensitivity analysis on the model using commercially available software (TreeAge Pro 2012, R2.3; TreeAge Software, Inc) to determine whether the total cost depended on the complication rate and to determine which route on the decision tree was most cost-effective (Figure 2).

### Results

Sensitivity analysis was applied demonstrating that the decision tree model was sensitive to a complication rate of 17.7% (Figure 2). In our decision tree model, regardless of the complication rate, intraoperative CT was always the more expensive option secondary to the increased OR time added by the use of intraoperative imaging. When we compared the decision to obtain postreduction imaging with no imaging, the breakpoint was 17.7%. At a complication rate requiring return to the OR of greater than 17.7%, obtaining postoperative panorex radiography is the more cost-effective option. At lower complication rates, no postoperative imaging is the more cost-effective choice.

Assuming the mean OR charge to fix a mandibular fracture is rather constant at a given institution, the model is sen-

### Table. Decision Tree Model OR and Imaging Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge, $</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>2046</td>
<td>UVA billing</td>
</tr>
<tr>
<td>Panorex radiography</td>
<td>313</td>
<td>UVA billing</td>
</tr>
<tr>
<td>Intraoperative 3-dimensional fluoro</td>
<td>620</td>
<td>UVA billing</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>30,205</td>
<td>UVA CDR (review of last 100 patients)</td>
</tr>
<tr>
<td>Complication</td>
<td>29,047</td>
<td>UVA CDR (review of last 6 complications)</td>
</tr>
<tr>
<td>Variable rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequate reduction, proportion</td>
<td>0.99</td>
<td>Bali and Lopes, 2004</td>
</tr>
<tr>
<td>Complication</td>
<td>NA</td>
<td>Literature rates vary (9%-25%)</td>
</tr>
</tbody>
</table>

Abbreviations: CDR, clinical data repository; CT, computed tomography; NA, not applicable; OR, operating room; UVA, University of Virginia. *Unless otherwise indicated, data are expressed as US dollars.

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**Figure 2. Sensitivity Analysis of Cost vs Complication Rate**

The decision tree model was sensitive to a complication rate of 17.7%. IOCT indicates intraoperative computed tomography.
sitive to small differences in imaging modality costs. However, the OR charges overwhelm the small incremental charges associated with each imaging modality, and varying the OR charge changes the breakpoint for imaging choice significantly. To account for different OR charges at different institutions, a 2-way sensitivity analysis was performed (Figure 3). This analysis generalizes the model and allows surgeons at different institutions to determine when they should choose panorex radiography and when they should choose no imaging based on their OR costs and complication rates. Plotting the institutional cost and individual complication rate in Figure 3 indicates the cost-effective modality.

## Discussion

In clinical decision-making algorithms, decision points often become standard practice with little evidence. As the evidence for or against the decision point builds, that standard of practice shifts. In many institutions, postreduction imaging is still the standard of care. Recent evidence, however, has suggested that postreduction imaging is unnecessary because it rarely alters clinical decision making. The added negative aspects of imaging associated with radiation exposure, delayed discharge, and perceived increased cost have resulted in a call to abandon this practice. However, most of these studies have not fully taken into account the issues of cost as it relates to the experience of the surgeon.

In our decision tree analysis using local cost data, we found that the complication rate significantly affects the cost-effectiveness with a breakpoint at 17.7%. A complication consisted of any event that would prompt the surgeon to consider returning to the OR. Such examples include infection, nonunion, malunion, delayed union, objective malocclusion, or hardware extrusion. Surgeons with historical complication rates of 17.7% or more would be best advised to obtain routine postreduction imaging, whereas those with rates less than 17.7% should not.

The specific rate for our institution, however, is not important. Rather, this model’s demonstration that cost-effective decision making depends on the individual surgeon’s complication rate matters. This guideline is more helpful than a generalized prescription that postreduction imaging is necessary or unnecessary.

This knowledge prompts the surgeon to analyze his or her operative data to determine his or her specific complication rate and the charges to fix a mandibular fracture at his or her institution. From these data, the surgeon can use the 2-way sensitivity analysis in Figure 3 to determine whether routine postoperative imaging as part of his or her individual practice will apply cost savings to the health system. Practice improvement studies of this type can be performed on an ongoing basis well after residency and may represent the type of data collection and reflection for which the Maintenance of Certification is striving.

As the surgeon gains experience, a reduction in postoperative complications should follow. The utility of postreduction imaging as part of routine practice at that point could no longer be necessary. In addition, obtaining a postoperative panorex radiograph can be very useful for immediate feedback and learning because fractures that seemed perfectly aligned in the OR may have some radiologic inadequacy. A postoperative radiograph allows the surgeon to assess the adequacy of the reduction and to determine whether the surgical procedure performed went as planned. This type of immediate feedback allows the surgeon to implement the appropriate changes to avoid the same mistakes in subsequent patients. A breakpoint such as that proposed by the present study can be used as a benchmark as one ascends the learning curve.

The major limitation of this study is that cost was determined using OR charges. Charges do not reflect the real cost to the system, but they are the only consistent financial number associated with a surgical procedure; collections and reimbursement vary widely based on the payer and patient. A lower, more realistic cost would make the model more sensitive to the choice of imaging modality and make obtaining routine panorex radiography more efficient most of the time (Figure 3).

## Conclusions

The utility of postreduction imaging from the standpoint of cost-effectiveness depends on the complication rate of the facial traumatologist. Therefore, a generic dictum regarding routine postreduction imaging is not helpful. Rather, the facial traumatologist should use his or her prior experience and individualized complication rate to determine whether routine postreduction imaging is necessary. This practiced-based learning approach encourages the facial traumatologist to navigate the health care system responsibly while caring for his or her patient effectively.
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Drafting of the manuscript: Barrett, Halbert, Fiorillo, Christophel.
Critical revision of the manuscript for important intellectual content: Barrett, Christophel.
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REFERENCES


