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Creating a "Box View" of Periprosthetic Distal Femur Fractures Using Three-Dimensional Image Processing

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Abstract

Retrograde intramedullary nailing of periprosthetic distal femur fractures requires an open box femoral component. However, presence of an open box is difficult to determine using standard imaging. The objective of this study is to present a novel three-dimensional (3D) image processing and analysis technique, called the "Box View," which addresses this problem. Twelve patients undergoing revision total knee arthroplasty's pre-operative computed tomography scans were reformatted to subtract the tibia, and a 3D Box View movie was generated. The method of this study included 4 attending surgeons and 6 residents who reviewed radiographs, computed tomography (CT), and Box View images, then interpreted presence of an open box. Inter-observer reliability was assessed with 2-factor analysis of variance (ANOVA) and sensitivity/specificity of the Box View versus radiograph and CT was performed with a Stuart-Maxwell test. The results of this study showed that the Box View was 81% sensitive and 97% specific for identification of an open box, with a positive predictive value of 100% and a negative predictive value of 85%. The Box View's specificity was significantly better than radiographs (53%, P=.003) and CT (50%, P=.002), and sensitivity (81%) was significantly better than CT (34%, P<.001) but not radiographs (77%, P=.63). Inter-observer agreement with the Box View was 0.88, radiographs was 0.65 and CT was 0.09. The conclusion was that the Box View is a novel and useful pre-operative planning tool for treatment of distal femur fractures with high sensitivity and specificity, positive and negative predictive value, and inter-observer reliability.

Abbreviations

3D = three-dimensional
ANOVA = analysis of variance
CT = computed tomography
IMN = intramedullary nail
TKA = total knee arthroplasty

Introduction

As the number of total knee arthroplasties (TKAs) performed annually continues to grow, so does the incidence of periprosthetic distal femur fractures. The incidence of supracondylar femur fractures after TKA ranges from 0.3-2.5% and 5-year incidence of all fractures after primary and revision TKA is 0.6% and 1.7%, respectively.[1,2]

The treatment algorithm for these injuries is evolving. Displaced periprosthetic distal femur fractures are almost universally operative injuries, and recent studies have evaluated the risks and benefits of distal locking plate versus retrograde intramedullary nail (IMN) fixation. Benefits of retrograde IMN fixation include immediate weightbearing and range of motion, a high union rate, and a low complication rate.[3-6]

Assessing standard imaging for whether the femoral component of a TKA is compatible with a retrograde IMN is difficult. A cruciate-retaining prosthesis technically does not have an open box but has a cutout in the femoral component between the femoral condyles that allows for retrograde femoral intramedullary nailing through the intercondylar notch. Posterior-stabilized femoral components can contain an open or closed box within the intercondylar notch to accommodate the tibial post. A closed box design precludes placement of a retrograde IMN, but an open box design does not. Conventional radiographs and even cross sectional imaging can be unreliable in determining if the femoral component is an open or closed box design.

Routine pre-operative imaging of displaced periprosthetic distal femur fractures includes full length femur radiographs and dedicated knee radiographs of the injured extremity. Difficulty in manipulating the injured extremity for precise radiographs can limit their diagnostic capability in determining whether a femoral component has an open box. The role of routine cross-sectional imaging, especially computed tomography (CT), during pre-operative planning is less clear but is most valuable when deciding between retrograde IMN and locked plate fixation. CT has clear advantages over plain radiographs in evaluating the amount and quality of distal bone stock available for fixation, but conventional CT similarly fails to determine whether the existing TKA femoral component is both compatible with retrograde intramedullary access (ie, a cruciate-retaining or open box design posterior-stabilized femoral component) and sufficiently anterior for proper placement of retrograde IMN fixation.

The introduction of three-dimensional (3D) reconstruction and ghost view projections has further increased the value to pre-operative CT imaging. 3D-CT of periprosthetic distal femur fractures can be used to produce an informative image of the femoral component, a "Box View."

Methods

With Stanford University institutional review board approval (#10669), 12 patients who had undergone revision total knee arthroplasty and had pre-operative CT scans of the operative knee were identified from an institutional database. Of the 12 patients identified, 9 had a femoral prosthesis amenable to an intramedullary implant (ie, cruciate-retaining or open box design posterior-stabilized) and 3 did not (ie, closed box design posterior-stabilized). All had available access for retrograde IMN determined definitively at the time of revision surgery. Four orthopaedic trauma fellowship-trained attending surgeons and 6 residents reviewed a randomized list of radiographs, axial CT scans, and the Box View for each patient. Data was collected from reviewers by a paper survey where they were asked to view each image and indicate the presence of an "open" box, a "closed" box, or "unsure."

Radiographic Technique

Non-contrast axial CT scans were performed. Raw CT data was transferred to a General Electric Advantage Windows 2.0 workstation (General Electric Healthcare, Chicago, IL) where it was loaded in reformat and segmented. Reformatting was done in the plane of the femoral component box to produce the largest possible cross-sectional view of the box. In developing this protocol, the team took advantage of the fact that the box was perpendicular to the mechanical axis of the femoral component. The segmentation was performed using paint on slices to exclude the tibia (**Figure 1**, red oval). This was done to prevent signal from the tibia and tibial component from obscuring interpretation of the femoral component box. The key image was a transparent volume projection perpendicular to the box (**Figure 1**, green line). This was essentially an *en face* view of the box. At this point a 36-image, 360° rotational movie was then created using a transparent volume rendering setting. The movies were easily interpreted to determine if the implant has a closed box (**Figure 2**, A and B showing standard radiographs, C showing standard axial CT cuts, and D showing the box view) or open box (**Figure 3**, A and B showing standard radiographs, C showing standard axial CT cuts, D showing the box view, and E and F showing post-operative standard radiographs).

Statistics

Inter-observer reliability was assessed for interpretation of plain radiographs, axial CT images, and Box View using 2-factor analysis of variance (ANOVA) without replication. The sensitivity and specificity of the Box View versus plain radiographs and the Box View versus CT were assessed using the Stuart-Maxwell test for marginal homogeneity. Statistical analysis was performed using Stata Release 15 (StataCorp LLC, College Station, TX).

Results

The sensitivity of the Box View was excellent (81%), as was the specificity (97%). The Box View had excellent positive (100%) and negative (85%) predictive values in this non-fractured test population (**Table 1**).

The sensitivity and specificity were compared for the Box View versus plain radiographs as well as for the Box View versus CT using Stuart-Maxwell test for marginal homogeneity (**Table 2**). The Box View's specificity (97%) was significantly better than both plain radiographs (53%,P= .003) and CT (50%, P=.002). The Box View's sensitivity (81%) was significantly better than CT (34%, P<.001) but not plain radiographs (77%, P=.63).

Intra-class correlation showed excellent inter-observer agreement with the Box View (0.88). This differed from the agreement with plain radiographs (0.65) and CT (0.09, **Table 3**).

Discussion

Whether the femoral component of a TKA is amenable to retrograde IMN is often unclear based on plain radiographs and axial CT scan. In geriatric patients, lateral locked plating of supracondylar femur fractures has limitations mainly due to failure rates.[7] There have been conflicting results regarding outcomes of lateral locked plating versus retrograde IMN, with a recent study finding no functional difference between the 2 treatments at 1 year, but others showing potential benefits to IMN fixation for coronal plane deformity and early patients outcomes.[7-9] Combination of lateral locked plating with IMN fixation has shown improved rates of unplanned reoperation and varus collapse.[10] Ultimately, choice of fixation in periprosthetic distal femur fracture is multifactorial and includes an evaluation of available bone stock, the femoral component of the TKA, and surgeon preference, but incorporation of IMN alone or in combination with lateral locked plating is a growing trend when it is feasible. Despite a growing appreciation of the advantages of femoral nailing, there is a lack of efficient diagnostic options for assessing if a fracture is amenable to nail fixation.[11] The Box View technique offers an efficient method for pre-operatively distinguishing fractures potentially amenable to retrograde IMN fixation. The technique produces images which are easily and reliably interpreted. Interobserver agreement demonstrates that the technique is highly reproducible across multiple levels of training. Additionally, the high sensitivity and specificity of the Box View when compared with both standard formatting of CT imaging makes it a valuable technique when CT imaging is used in pre-operative planning for peri-prosthetic distal femur fracture. Although there was not a statistical difference in sensitivity of the Box View compared to plain radiographs, it has a much higher specificity.

This technique has a number of limitations. The focus of this study was on identifying the presence of an open box component, but did not include any evaluation of surgeon ability to use the Box View method to accurately measure the size of the open box aperture, which can also im-

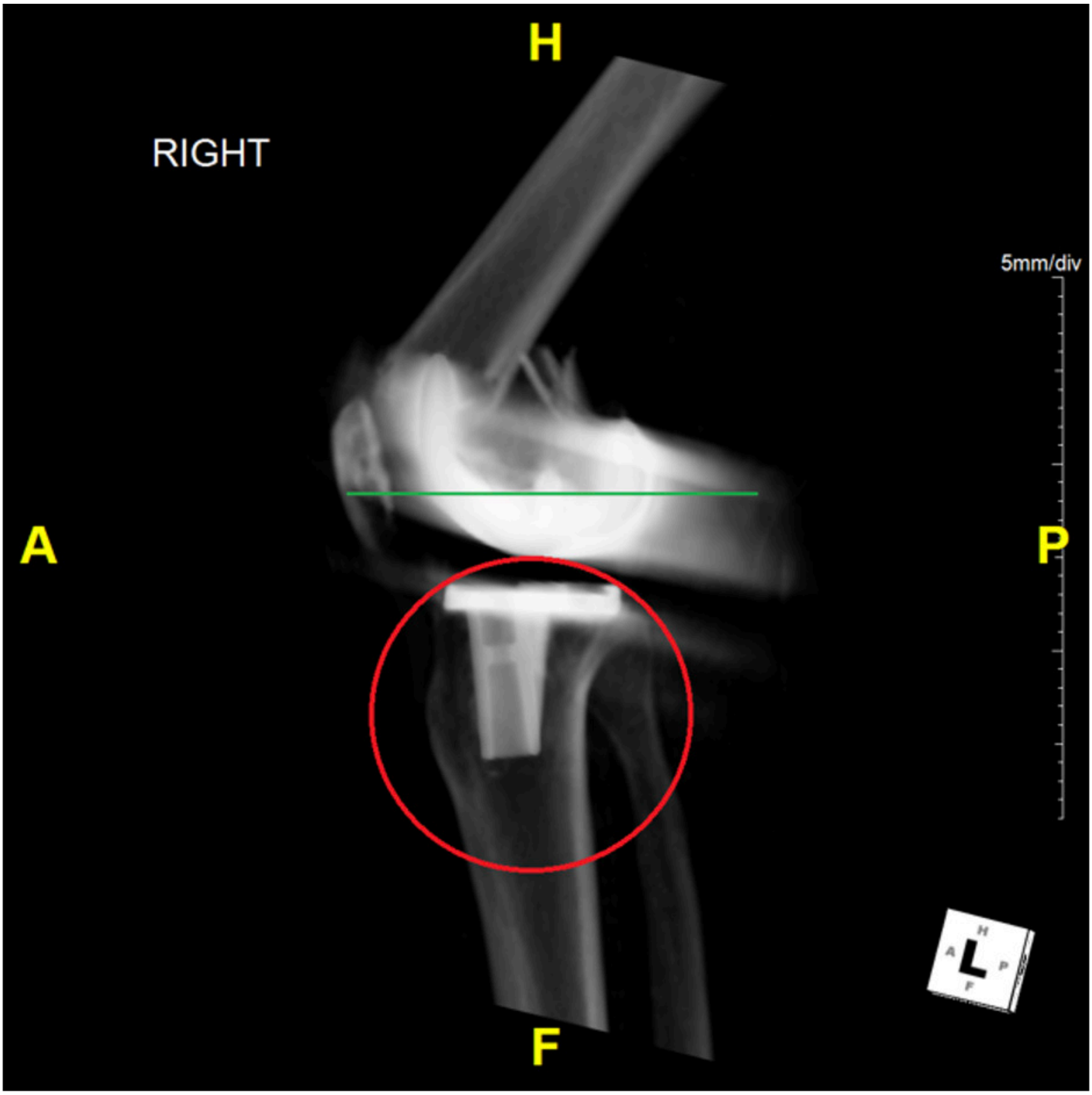

Figure 1. Box View Image Processing.

After segmentation, reformatting, and reconstruction, the volume representing the tibia (red oval) is subtracted. In the second step a ghost view is projected along an axis perpendicular to the green line to give an axial view of the total knee arthroplasty (TKA) femoral component box. A=anterior, P=posterior, H=head, F=foot.

pact the feasibility of utilizing a retrograde IMN.[12] The most accurate way of determining whether a femoral component can accept a retrograde IMN of a given size remains to obtain the operative report from the index TKA surgery and every attempt should be made to obtain this information if possible. However, in cases when the operative report is unavailable within a reasonable timeframe, the Box View can be a useful technique for pre-operative planning. The Box View is an adjunctive technique which requires a radiographic technician familiar with image post-processing, including volumetric subtraction and ghost view projection. It also requires a pre-operative CT. However, even prior to implementation of this technique, non-contrast CT was often part of pre-operative workup to assess intact bone volume and to evaluate the femoral component. Furthermore, multiple attempts to manipulate the unstable fracture to obtain quality orthogonal radiographs can result in both increased radiation to the patient as well as significant patient discomfort. In this setting, the Box View reconstruction technique is fast and effective and imparts minimal additional risk to the patient. Future investigation of the Box View technique should include evaluation of the accuracy of measuring the box aperture for the purpose of evaluating the maximum diameter IMN that can be accommodated. Overall, this Box View has the advantage of facilitating and improving preoperative planning in supracondylar periprosthetic distal femur fractures above a well-fixed TKA.

Figure 2. Example of the Unreliability of Conventional Imaging Methods and the Potential Value of the Box View.

A 75-year-old female with a remote history of left knee TKA who sustained a mechanical ground level fall and presented with chief complaint of left knee pain and deformity. A: Anteroposterior knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. B: Lateral knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. C: Axial CT images appear to demonstrate an open box. Intraoperatively a nail could not be passed, and the fracture was treated with a lateral plate. D: Retrospective post-operative Box View clearly demonstrates a closed box.

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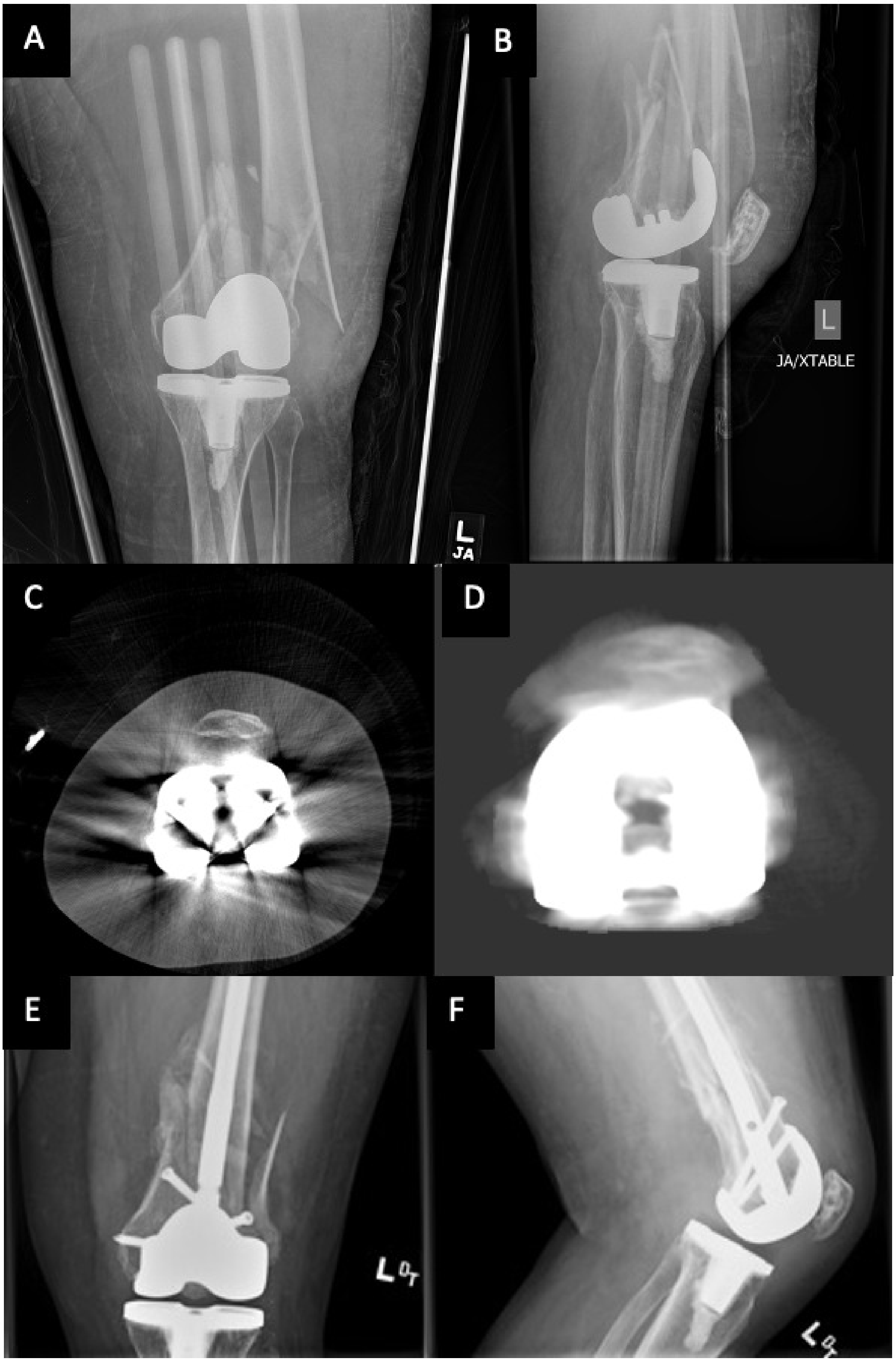

Figure 3. Example of Accurate Identification of an Open Box Using the Box View.

64-year-old female with a one-year history of well-functioning left TKA presenting with left knee pain and inability to bear weight after a mechanical ground level fall. A: Anteroposterior knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. B: Lateral knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. C: Axial CT image is unclear as to whether the femoral component has a closed or open box. D: Box View clearly demonstrates an open box design amenable to IMN. E: Anteroposterior knee radiograph after intramedullary nailing. F: Lateral knee radiograph after intramedullary nailing.

Table 1. Results for the Interpretation of Plain Radiographs, Computed Tomography (CT) and Box View for the Validation Sample in Pre-operative Identification of Open Box Femoral Components.

	Sensitivity	Specificity	PPV	NPV
Plain radiograph	77	53	95	76
Computed tomography (CT)	34	50	82	56
Box View	81	97	100	85

PPV=Positive predictive value; NPV=Negative predictive value.

Table 2. Comparison of Box View, Plain Radiograph, and Computed Tomography Test Performance in Identification of Open Box Design

	Stuart-Maxwell	df	*P*-value[a]
Box view versus plain radiograph			
Sensitivity	0.92	2	.632
Specificity	11.36		**.003**
Box View versus computed tomography			
Sensitivity	38.47	2	**<.001**
Specificity	12.44	2	**.002**

df=Degrees of freedom
[a]Stuart-Maxwell test for marginal homogeneity

Table 3. Intra-class Correlation Demonstrating the Inter-observer Reliability of Interpretation of Plain Radiographs, Computed Tomography, and Box View in the Validation Sample

	Inter-observer agreement quotient[a]
Plain radiograph	0.65
Computed tomography (CT)	0.09
Box View	0.88

[a]2-factor analysis of variance (ANOVA)

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