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Identification of Postoperative Step-Offs and Gaps With Brodén's View Following Open Reduction and Internal Fixation of Calcaneal Fractures

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Abstract

Background: To date, there is no consensus regarding which postoperative imaging technique should be used after open reduction and internal fixation of an intra-articular calcaneal fracture. The aim of this study was to clarify whether Brodén's view is sufficient as postoperative radiologic examination to assess step-offs and gaps of the posterior facet.

Methods: Six observers estimated the size of step-offs and gaps on Brodén's view in 42 surgically treated intra-articular calcaneal fractures. These findings were compared to postoperative CT scans (gold standard). Inter- and intraobserver reliability were calculated and compared using intraclass correlation coefficients (ICCs).

Results: An accuracy of approximately 75% for both step-offs and gaps was found in foot and ankle experts. Less experienced observers correctly identified step-offs and gaps in approximately 62% of cases on fluoroscopy and in 48% on radiographs. Interobserver reliability for intraoperative fluoroscopy as well as postoperative radiographs was fair for step-offs, whereas interobserver reliability for gaps was excellent. Intraobserver reliability showed a low level of agreement for intraoperative fluoroscopy, in contrast to postoperative radiographs with excellent agreement for step-offs and good agreement for gaps.

Conclusion: Our results show that especially for more experienced foot and ankle surgeons, in the majority of fractures, Brodén's view accurately showed step-offs and gaps following open reduction and internal fixation. Interobserver reliability showed a fair level of agreement for step-offs and excellent agreement for gaps. Intraobserver reliability was only enough for radiographs, not for fluoroscopy.

Level of Evidence: Level IV, case series.

Keywords: calcaneus, fracture, ORIF, hindfoot, Brodén's view, step-off, gap

Introduction

Before the dawn of computed tomography (CT) scanning, Brodén described a technique to depict the posterior subtalar joint in calcaneal fractures.[5] Originally, he described 4 projections in endorotation with the beam angled at 10, 20, 30, and 40 degrees caudocranial, so that the posterior part followed by the anterior part of the subtalar joint was visualized.[5] Currently the CT scan is used more often to obtain a more detailed image of the hindfoot.[9] However, in relation to costs and radiation exposure of the CT scan, Brodén's view is still used intra- and postoperatively.[21,24,25] The need for postoperative CT scan is open for debate. Nonetheless, many authors have advised to either evaluate reduction or position of implants and predict outcome. Janzen et al concluded that CT scanning performed after 1 to 11 years after fracture shows that degenerative changes and incongruity of

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the posterior subtalar joint correlate with poor clinical outcome.[14] In contrast, Qiang et al showed that restoration of Böhler's and Gissane's angle on postoperative CT significantly correlates with better clinical outcome.[22] Magnan et al also agrees that realignment and restoration of the calcaneal height on CT are associated with better clinical outcomes.[18] In addition, although not identified intraoperatively, a postoperative CT scan can reveal the presence of screws in the subtalar joint and affect postoperative management.[26]

Moreover, there are a number of studies indicating that using intraoperative 3-dimensional imaging detects more reduction errors compared to conventional fluoroscopy and it is suggested that usage of this imaging technique could improve articular reductions and may also improve outcomes.[11,12] However, intraoperative availability of a scanner is not always guaranteed. When deciding what imaging technique is appropriate, individual patient characteristics, costs, radiation exposure, and artifacts by material used for fixation should be taken into account.[4]

Kwon et al studied the relationship between coronal CT scans and Brodén's view in calcaneal fractures preoperatively. The authors concluded that "the fracture line on Brodén's view shows laterally compared to CT and surgeons should consider that the facture line at the lateral to posterior facet might be an intra-articular fracture line."[17] This gives us reason to believe that there is a qualitative difference between these imaging techniques, which could influence postoperative evaluation. No research has been performed comparing both techniques postoperatively. The aim of this study was to clarify whether Brodén's view is sufficient as postoperative radiologic examination to assess step-offs and gaps of the posterior facet following open reduction and internal fixation of displaced intra-articular calcaneal fractures.

Methods

Data Collection

All consecutive patients who underwent primary open reduction and internal fixation via the sinus tarsi approach (STA) for an intra-articular calcaneal fracture in our clinic between August 2012 and October 2017 were prospectively registered in a database. Patients, fit for surgery, with significant displacement (articular surface more than 2 mm displacement, Böhler's angle less than 15 degrees, varus/valgus deformity of more than 5 degrees) were treated via open reduction and internal fixation. Only patients who met the criteria of having a complete set of intraoperative fluoroscopy images including Brodén's view, a postoperative CT scan, and follow-up Brodén's view radiographs within 6 months after surgery were included. In our clinic, a 15-degrees angle is used for producing a single image of the subtalar joint. At that particular angle, the posterior part of the subtalar joint is well visualized. An independent observer selected the intra- and postoperative Brodén's view that depicted the posterior subtalar joint best and excluded images lacking quality.

Of 141 fractures meeting the inclusion criteria, 50 were randomly selected for inclusion in this study with the intention to construct reasonable surveys, which would take approximately 15 minutes to complete (random number generator, Microsoft Excel, Microsoft corporation, Redmond, WA). Eight patients were excluded because of a lack of qualitative acceptable radiographs, such as a screw or plate projecting over the posterior facet. The final population thus consisted of 38 patients with 42 operatively treated fractures.

Of the unilateral fractures, 17 (40%) were left-sided and 17 were right-sided. The median age at time of surgery was 43 years (interquartile range 35-59). The population consisted of 29 (76%) men and 9 (24%) women. Twenty-nine (69%) fractures were reconstructed using plates and 13 (31%) by using screws only. The median time between surgical fixation and a postoperative CT scan was 1 day, whereas the median time between surgical fixation and follow-up Brodén's view was 57 days, ranging between 46 and 66 days.

A panel consisting of 3 trauma surgeons and 3 residents in general surgery with at least 4 years of experience in foot and ankle trauma were invited to independently evaluate all Brodén's view intraoperative fluoroscopies and postoperative radiographs. Two of the observers (1 and 2) were specialized foot and ankle trauma surgeons with more than 10 years of experience. The panel was requested to estimate the size of the step-off and gap, if present, in 4 categories. Similar to the criteria described by Sanders et al, a value of 0 to <1 mm was considered an anatomic reduction, 1 to <3 mm a near anatomic reduction, 3 to <5 mm an approximate reduction, and >5 mm a failure of reduction.[23] The panel was also able to score the step-off and/or gap as "not judgeable." To mimic clinical practice assessments were performed on a standard PC monitor. During both assessments, at least 1 week apart, the members of the panel were blinded using web-based surveys containing randomly numbered exported high-resolution images without patient information created using Google Forms (Google, Mountain View, CA). To ensure correct application of estimation values, an illustrated explanation was provided before starting the assessments (Figure 1).

One trauma surgeon and an independent researcher evaluated reduction of the posterior facet on postoperative CT scan using picture archiving and communication system (PACS). When disagreement occurred, the surgeon and researcher came to a consensus. The order of evaluation of CT scans was in a randomized fashion and evaluated using transverse images and reconstructions in the coronal and sagittal plane at a thickness of 1 mm. Reduction was measured in the coronal plane as often as possible as this corresponded most with Brodén's view.[17]

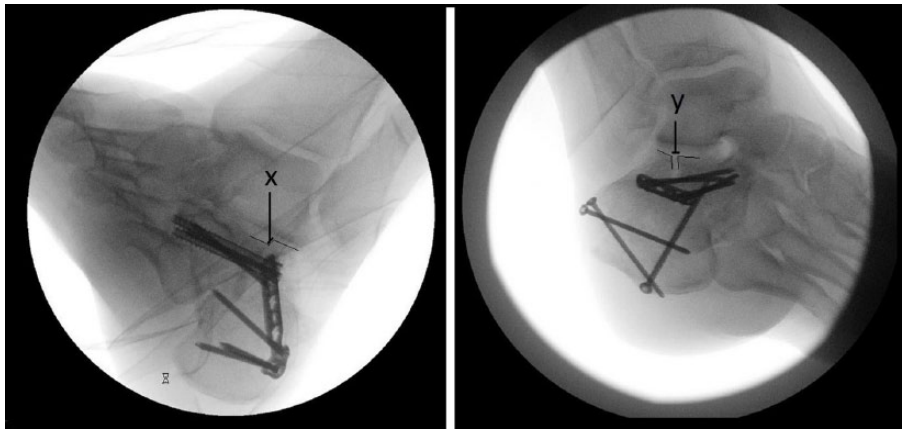

Figure 1. Assessment of a step-off in height (*x*) and a gap in width (*y*) on 2 intraoperative fluoroscopies showing the Brodén's view with categorical options: (1) 0 to <1 mm: anatomic reduction; (2) 1 to <3 mm: near anatomic reduction; (3) 3 to <5 mm: approximate reduction; (4) >5 mm: failure of reduction; (5) not judgeable.

Statistical Analyses

To determine the relationship between intraoperative and postoperative Brodén's view and CT scan, the number of correctly identified step-offs and gaps per observer were calculated. Measurements on CT scan were used as the gold standard. In case an observer chose the option "not judgeable," this was taken into account when calculating percentages by considering this answer as incorrect. Six observers were subdivided into 2 groups consisting of 2 foot and ankle experts and 4 less experienced observers.

Interobserver reliability was calculated using intraclass correlation coefficient (ICC) because of multiple observers and multiple items scored, similar to previous research.[10] By using ICC, agreement by chance was taken into account for all observers and items. To calculate interobserver reliability, a 2-way random effects model with a mean of all measurements and absolute agreement was applied.[13,15] Observers were selected from a larger population of surgeons and residents, and we believe it was legitimate to generalize their results to any observer with the same characteristics. For intraobserver reliability, all images were reassessed in a different order with a 2-week interval. A 2-way mixed effects model, single measurements, and absolute agreement was used as recommended by Koo et al.[15] Based on the cut-off values of Cicchetti et al, an ICC of more than 0.60 was needed to be labeled as an agreement. An ICC value below 0.40 indicated poor reliability. Values between 0.40 and 0.59 were specified as fair. Good reliability was indicated by values ranging from 0.60 to 0.74. And finally ICC values between 0.75 and 1.00 indicate excellent reliability.[8]

Statistical analyses were performed using SPSS, version 24 (IBM Corp, Armonk, NY). Approval for this study was obtained from the Institutional Reviewing Board.

Results

The following fracture types of the Sanders classification were included: 29 (69%) type 2, 12 (29%) type 3, and 1 (2%) type 4 fracture. According to the Essex-Lopresti classification, 24 (57%) factures were tongue-type fractures and 15 (36%) were joint depression type fractures. Three (7%) were too comminuted to classify. Of 42 fractures, a step-off between 1 and 3 mm was displayed in 5 fractures on CT scan, and in 9 fractures a gap between 1 and 3 mm was visible. A gap combined with a step-off, both between 1 and 3 mm measured on CT scan, was observed in 3 cases. Finally, 1 fracture showed a step-off between 1 and 3 mm combined with a gap of 3 to 5 mm. Altogether 24 (57%) fractures were scored as anatomic reduction, 17 (40%) step-offs indicated near anatomic reduction, and 1 (2%) combined gap indicated approximate reduction. Overall anatomic or near anatomic reduction was achieved in 98% of all fractures based on the Sanders grading system.[23] All observers completed the surveys. The median duration of assessing 42 images was 11 minutes (interquartile range 6-19).

Performance on Brodén's view compared to the gold standard CT measurements of the overall group was as following: on intraoperative fluoroscopy, 64.3% of the step-offs and 67.9% of the gaps were correctly identified. On postoperative radiograph, 58.7% of the step-offs and 56.7% of the gaps were accurately recognized in size. When subdividing the group, foot and ankle experts scored a mean percentage of 72.6% on step-offs on fluoroscopy. Gaps on fluoroscopy showed an accuracy of 76.2%. Foot and ankle experts matched 77.4% of the radiographs with the CT measurements for both step-offs and gaps. Assessment option "not judgeable" was not used by the experts (Table 1).

Table 1. Foot and Ankle Experts' Performance—Correctly Identified Brodén's View Compared With CT Measurements.

	Intraoperative Fluoroscopy		Postoperative Radiograph		
Observer	Step-off, n (%)	Gap, n (%)	Step-off, n (%)	Gap, n (%)	Not Judgeable, n
1	30/42 (71.4)	33/42 (78.6)	31/42 (73.8)	32/42 (76.2)	0
2	31/42 (73.8)	31/42 (73.8)	34/42 (81.0)	33/42 (78.6)	0
Mean	72.6%	76.2%	77.4%	77.4%	

Abbreviation: CT, computed tomographic.

Table 2. Less Experienced Observers' Performance—Correctly Identified Brodén's View Compared With CT Measurements.

	Intraoperative Fluoroscopy		Postoperative Radiograph		
Observer	Step-off, n (%)	Gap, n (%)	Step-off, n (%)	Gap, n (%)	Not Judgeable, n
3	28/42 (66.7)	26/42 (61.9)	22/42 (52.4)	24/42 (57.1)	5
4	29/42 (69.0)	31/42 (73.8)	27/42 (64.3)	27/42 (64.3)	4
5	27/42 (64.3)	27/42 (64.3)	18/42 (42.9)	14//42 (33.3)	27
6	17/42 (40.5)	23/42 (54.8)	16/42 (38.1)	13/42 (31.0)	9
Mean	60.1%	63.7%	49.4%	46.4%	

Abbreviation: CT, computed tomographic.

Less experienced observers rated 60.1% of all step-offs correctly on fluoroscopy compared to CT measurements. Evaluating gap size on fluoroscopy showed an accuracy of 63.7%. This subdivision of the panel matched 49.4% and 46.4% of the radiographs with the CT measurements, for step-offs and gaps respectively. Assessment option "not judgeable" was used 4 (2.4%) to 27 (16.1%) times per observer by the nonexperts in both surveys combined (Table 2).

The interobserver reliability of intraoperative fluoroscopy and postoperative radiograph varied between 0.436 and 0.846. Based on the cut-off values of Cicchetti et al, the reliability of assessing step-offs on fluoroscopy and on radiographs is fair, respectively, an ICC of 0.535 (95% CI 0.276-0.729) and an ICC of 0.436 (95% CI 0.148-0.666).[8] Interobserver reliability was found to be excellent for judging fracture gaps, with an ICC of 0.846 (95% CI 0.751-0.913) for fluoroscopy and 0.807 (95% CI 0.664-0.897) for radiographs. All calculated values were found to be statistically significant (Figure 2).

Intraobserver reliability assessing step-offs on intraoperative fluoroscopy was not significant $P = .056$ (ICC 0.241). An ICC of 0.385 (95% CI 0.107-0.611) showed a low level of agreement for gaps on intraoperative fluoroscopy. This is in contrast to postoperative radiographs with excellent agreement for step-offs (ICC 0.772, 95% CI 0.615-0.870) and good agreement for gaps (ICC 0.696, 95% CI 0.499-0.825).

Discussion

The primary purpose of this study was to determine whether postoperative step-offs and gaps identified on CT scan following open reduction and internal fixation of displaced intra-articular calcaneal fractures can be accurately identified on Brodén's view. Foot and ankle experts correctly scored the size of step-offs and gaps on intraoperative fluoroscopy imaging and postoperative radiographs in approximately 75%. When focusing on the reduction aspect and imaging techniques separately, gaps are more likely to be identified correctly, and experienced observers perform better using radiographs. Less experienced observers were less accurate with percentages differing between means of 46.4% and 63.7%, depending on the reduction aspect and imaging technique. Gaps were more likely to be identified correctly using fluoroscopy than step-offs, whereas step-offs were best identified on radiographs for less experienced observers. This group of observers consistently performed better using fluoroscopy images rather than radiographs. Simultaneously, based on the number of times an image was scored as not judgeable, less experienced observers showed more hesitation answering the assignments. Moreover, this hesitation was also objectified by a variance in duration of the surveys. Surgeons with more experience completed the surveys quicker than all residents. To our knowledge, this is the first study of both imaging techniques for postoperative evaluation of reduction. Our results show that when evaluated by foot ankle experts, in the majority of fractures Brodén's view accurately showed step-offs and gaps postoperatively. This could lead to a reduction of CT imaging and accompanying costs and radiation exposure.

There were limitations to this study. Firstly, as noted before, Brodén's described his projection with the affected leg in endorotation and the angle of the beam differing from 10 to 40 degrees in the caudocranial direction. By doing so,

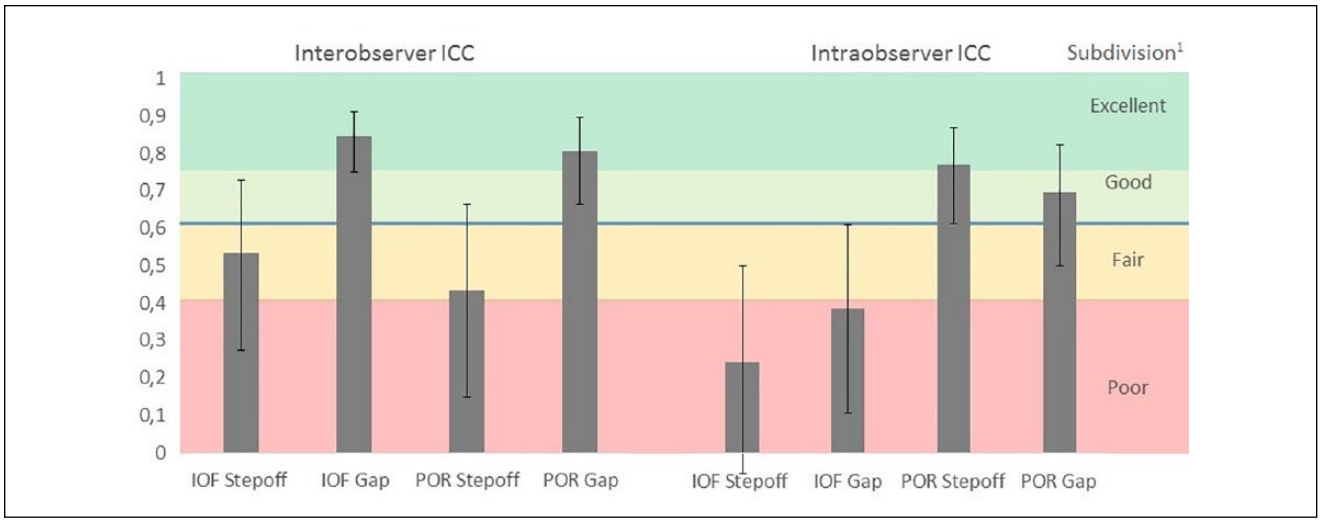

Figure 2. Inter- and intraobserver reliability calculated with intraclass correlation coefficient and subdivided based on guidelines of Cicchetti et al. (ICC, intraclass correlation coefficient; IOF, intraoperative fluoroscopy, POR, postoperative radiograph.)
[1]*Reference* 8.

the posterior part is visualized when the beam is aimed at 10 degrees and the anterior part of the subtalar joint is visualized with the beam angled at 40 degrees.[5] Intraoperatively, using the STA, especially the anterior portion of the subtalar joint is clearly visible, making the anterior Brodén's views less relevant.[3] Therefore, in our clinic, a 15-degree angle was used for producing a standardized single image of the subtalar joint postoperatively. At that particular angle, the posterior part of the subtalar joint was well visualized. In addition, the exact angle at which the fluoroscopy image was made intraoperatively is not known. This means that it is unclear how well the intraoperative image and postoperative, more protocolized, radiograph correspond to one another. This might be the reason for the lower intraobserver ICC for the intraoperative fluoroscopy images in comparison to the postoperative images. In addition to these difficulties of the execution of Brodén's view, another limitation to this study, inherently connected to the fact that only fractures following open reduction and internal fixation were included, is the fact that images containing obstructive implants were excluded. These images would probably otherwise have been labeled as not judgeable. Screws or plates projecting over the posterior facet and thereby hampering evaluation of the reduction is a weakness of 2-dimensional imaging and could be a reason to perform a CT scan. Furthermore, the step-offs and gaps were classified in 4 categories and not as continuous values. The decision to categorize the step-offs and gaps was based on the availability of an existing classification and for statistical purposes, since continuous values would have required more patients. Kurozumi et al and Sanders et al used 4 categories as well and linked them to outcome.[16,23] Using 3 categories, Buckley et al showed improved outcome if reduction was within 2 mm corresponding to the anatomic and near-anatomic categories.[6] In addition, gaps might be scored differently as well, as it is currently unclear if they have the same impact as step-offs.[2,20] The follow-up limit was set to 6 months. Most follow-up radiographs were made at 6 to 8 weeks. It is plausible that step-offs or gaps are visible on CT scan directly after surgery, but become more unclear on Brodén's view radiograph at follow-up after 6 months.[19] Several studies have shown that settling or "smoothing" of unfixed fragments of the articular surface of the calcaneus takes place postoperatively, especially in case of early exercise and weight bearing.[1,7] As this study was primarily aimed to determine the added value of Brodén's view instead of CT scan, we did not use patient-related outcome measures (PROMs). By using a percentage agreement for validating between achieved anatomic reduction on Brodén's view versus CT scan, we did not correct for agreement expected by chance. This might cause an overestimation of the level of agreement. We did cover this problem when calculating inter- and intraobserver reliability.[10,13] Finally, the current study focused only on step-off and gap as these are the parameters for which the Brodén's view is used. Other aspects, such as angulation, symmetry, height, and width or presence of bone fragments, are interesting topics for future studies, further investigating radiographs including axial and lateral views in comparison to CT scan.

Conclusion

Our results show that in the majority of fractures Brodén's view accurately visualized postoperative step-offs and gaps of the posterior facet, especially when evaluated by more experienced foot and ankle surgeons. This may lead to a reduction of CT imaging, accompanying costs, and

radiation exposure. Interobserver reliability showed a fair level of agreement for step-offs and excellent agreement for gaps. Intraobserver reliability was mainly sufficient for postoperative radiographs.

Declaration of Conflicting Interests

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