**Journal of Orthopaedic Trauma Publish Ahead of Print**
**DOI: 10.1097/BOT.0000000000000887**



# Any Cortical Bridging Predicts Healing of Supracondylar Femur Fractures After Treatment with Locked Plating

Patrick K. Strotman, MD[1] Email: pstrotman@lumc.edu
Madhav A. Karunakar, MD[2] Email: madhav.karunakar@carolinas.org
Rachel Seymour, PhD[2] Email: rachel.seymour@carolinas.org

William D. Lack, MD (corresponding author)[1]
Department of Orthopaedic Surgery and Rehabilitation
2160 South First Ave
Maywood, IL 60153-3328
Fax: 708-216-5858 Telephone: 617-529-8495 Email: wdlack@gmail.com

[1]Loyola University Medical Center, Maywood, IL
[2]Carolinas Medical Center, Charlotte, NC

**Conflicts of Interest and Sources of Funding:** The authors have no conflicts of interest with this study and no external funding was required.

Presented as a poster at the American Academy of Orthopaedic Surgeons Annual Meeting, New Orleans, LA. 2014, and at the Annual Meeting of the Orthopaedic Trauma Association, National Harbor, Maryland, October 7, 2016.

**IRB Approval:** This study was approved by an institutional review board.

**Abstract**

**Objectives:** To determine the accuracy and reliability of radiographic cortical bridging criteria in predicting the final healing of supracondylar femur fractures after treatment with locked plating.

**Design**: Retrospective review

**Setting:** Two level 1 trauma centers

**Patients/Participants:** We retrospectively reviewed the records at two level 1 trauma centers for patients who presented with supracondylar femur fractures (AO/OTA 33A, C) and were treated with locking plate fixation between 1/1/2004 and 1/1/2011. The final study population included 82 fractures after excluding patients with open physes (n=4), nondisplaced fractures (n=4), early revision for technical failure (n=4), or inadequate follow-up (n=42).

**Intervention:** Distal femur locking plate fixation

**Main Outcome Measurements:** Postoperative radiographs until final follow-up were assessed for cortical bridging at each cortex on anterior-posterior (AP) and lateral views. Images were analyzed independently by three orthopaedic traumatologists to allow for assessment of reliability. Final determination of union required both radiographic and clinical confirmation.

**Results:** Assessment for any cortical bridging was the earliest, accurate predictor of final union (95.1% accuracy at four months postoperatively), when compared to criteria requiring bicortical bridging (93.9% accuracy at 6 months) and tricortical bridging (78% accuracy at 21 months). Any cortical bridging demonstrated a higher interobserver reliability (kappa=0.73) relative to bicortical (kappa=0.27) or tricortical bridging (kappa=0.5).

**Conclusions:** Our results for plate fixation of supracondylar distal femur fractures mirror those previously described for intramedullary nailing of tibia shaft fractures. Any radiographic cortical bridging by four months postoperatively is an accurate and reliable predictor of final healing outcome following locking plate fixation of supracondylar femur fractures. Assessment for bicortical or tricortical bridging is less reliable and inaccurate during the first postoperative year.

**Level of Evidence:** Diagnostic Level III. See Instructions for Authors for a complete description of levels of evidence.

**Key Words:** femur; fracture; healing; union; nonunion

## Introduction

Distal femur fractures account for approximately 6% of all femur fractures.[1] These injuries demonstrate a bimodal distribution with young patients presenting after high energy trauma and elderly patients generally presenting after low energy falls from standing height.[2] The incidence of these fractures is likely to increase in parallel with the aging population and as medicine continues to make advances in acute trauma care. Locking plates are frequently used for fixation of supracondylar femur fractures, particularly in the setting of osteoporosis.[3, 4]

However, this treatment has been increasingly associated with reports of deficient callus, nonunion (14%), implant failure (6-20%), and a need for secondary procedures with bone grafting (12%).[3-19] Systematic reviews report a wide variation in healing-related complications (0 to 32%) and a 3.5 fold increase in nonunion with locking plates (5.3%) compared to intramedullary nailing (1.5%).[8, 9] Reported rates of healing complications are highly dependent upon follow-up, with 50% of implant failures reported to occur more than 6 months postoperatively.[8] Outside of implant failure, there is no consensus regarding the radiographic and clinical criteria used to assess fracture healing.

Among radiographic criteria, studies have found cortical bridging to be a relatively reliable finding that predicts mechanical strength better than measures such as callus area and quality.[20-25] Recent studies including those satisfying FDA standards have required radiographic bridging of three cortices to document a healed fracture.[24-26] However, the number of bridged cortices required for "normal healing" at specific postoperative intervals remains undefined. Additionally, cortical bridging is particularly difficult to assess in the setting of plate fixation, as the construct may obscure one or more cortices on standard radiographic views.

The current literature employs varying definitions of radiographic union, complicating direct comparison between studies.[6] With limited objective data defining how cortical bridging progresses over time, criteria used to predict union remain the subject of debate. Ideally, a discriminating tool could accurately identify fractures bound for union versus nonunion based on information available in the first few months after injury.

The purpose of this study was to determine the accuracy and reliability with which the time to achieving radiographic milestones (any cortical bridging, bicortical bridging, or tricortical bridging) predicts the final healing outcome of supracondylar femur fractures treated with locking plate fixation.

**Patients and Methods**

A retrospective review was performed of supracondylar femur fractures (AO/OTA 33A, C) treated with locked plating at two level 1 trauma centers between 1/1/2004 and 1/1/2011.[26] The final study population combined the two series of consecutive cases at both institutions and included 82 fractures (14 periprosthetic) after exclusions for open physes (n=4), nondisplaced fractures (n=4), fractures which underwent planned revision (i.e. bone grafting procedure to address segmental defect) within the first four months of presentation (n=4), and inadequate follow-up (n=42).

All study patients were treated with stainless steel (n=50) or titanium constructs (n=32). Definitive surgery was generally performed within one to four days from time of injury, with all patients undergoing definitive fixation within two weeks from injury. There did exist some variation in postoperative weightbearing protocols depending on the treating physician, patient, and injury characteristics. The majority of patients were made touchdown weightbearing following surgery. Advancement of weightbearing was dependent on factors such as radiographic analysis of the injury, the construct employed, and preference of the treating surgeon. However, all patients were allowed to bear full weight on the operative extremity within ten weeks of surgery.

Adequate radiographic and clinical follow-up was defined by meeting one of the following criteria: (1) documentation by the treating surgeon that the fracture was healed based on clinical evaluation (no pain at fracture site with unassisted weightbearing) and radiographs showing multiple cortices bridged with no visible fracture lines or (2) diagnosis of nonunion as defined by lack of progressive healing, construct failure, and/or presence of pain/swelling. Clinic notes were reviewed to ascertain when the treating surgeon declared the fracture a union or nonunion and ensured correlation with documentation detailing each patient's subjective report of pain and function, clinician's physical examination, and clinician's interpretation of serial radiographs. If patients did not have a follow up visit accompanied by biplanar radiographs centered on the distal femur every four to eight weeks (depending on surgeon preference and clinic availability), they were excluded from the study. Patients were also excluded if they lacked full radiographic healing and failed to return for follow-up. Typical follow-up intervals were at 2 weeks, 6 to 8 weeks, 3 to 4 months, 6 months, 9 months, and 1 year.

Aside from patients excluded from the study who had segmental defects treated with staged bone grafting, no patients underwent early advanced imaging or surgical treatment for nonunion. This was confirmed through the review of operative notes, clinical notes, and serial radiographs for all patients treated for distal femur fractures in the study period at the two institutions. Surgeons were additionally queried to ascertain their approach, and this was the preferred approach of all surgeons involved during the study period.

Plain radiographs were assessed for callus formation and cortical bridging by examining each cortex on both AP and lateral views of all postoperative radiographs through final follow-up. Cortical bridging was defined by callus formation continuously spanning between the proximal and distal segments. This did not require complete resolution of fracture lucency,

however, this was required for later declaration of union. Assessments of plain radiographs were made independently by three orthopaedic traumatologists and these assessments were analyzed for interobserver reliability. These assessments were made for the overall presence of bridging callus and the number of cortices bridged. Observers were not assessed on whether they agreed on which specific cortices were bridged (anterior, posterior, medial, or lateral). All patients' records were analyzed in their entirety to determine if late healing complications occurred in patients previously declared healed.

Each fracture case was assessed for union versus nonunion; length of time to form any postoperative callus; and length of time to achieve varying degrees of cortical bridging. Furthermore, patient age, mechanism of injury, pre-injury smoking status, diagnosis of diabetes, and identification of open versus closed fracture were also documented.

All statistical analyses were performed using SPSS for Windows, Version 13.0 (SPSS Inc., Chicago, IL). Receiver operator characteristic (ROC) curve and chi square analyses were used to determine the predictive accuracy of each criterion throughout the postoperative period. Univariable and multivariable cox proportional hazards models were performed to examine the impact of patient demographic and injury characteristics on time to cortical bridging. A p-value of $<0.05$ was considered statistically significant. Assuming an alpha value of 0.05, a power analysis required 40 fractures to achieve 85% power.

This study was approved by an institutional review board at both trauma centers.

**Results**

82 supracondylar femur fractures that met inclusion criteria were followed clinically to a final healing outcome (i.e. either clinically and radiographically healed during follow-up or diagnosed as a nonunion). Of the 82 cases, 49 were female (59.8%) and 33 were male (40.2%). All were skeletally mature. The average age of the study population was 57.8 +/- 20.3 years. The majority sustained a high energy injury (58.5%). Twenty-four patients (29.3%) presented with an open fracture. A minority of patients were documented tobacco users (25.6%). Fourteen patients (17.1%) had past medical history notable for diabetes mellitus.

Median time required to reach a final healing outcome was 9.5 months (range 2 to 49 months). Ten of 82 patients (12%) were diagnosed with nonunion at a median time of 8 months (range 5 to 22 months) postoperatively. The cumulative percentage of fractures deemed healed without intervention was 6 (7%) at four months, 16 (20%) at six months, 32 (39%) at nine months, 45 (55%) at 12 months, 49 (60%) at 14 months, and 73 (89%) at final follow up. Of 10 nonunions, five were diagnosed secondary to construct failure and five were diagnosed by clinical evaluation and failure of progressive radiographic healing. No patient who was declared united by the treating surgeon was later found to have implant failure or require an intervention due to healing-related complications.

A high energy mechanism of injury was a significant prognostic indicator for nonunion, as nonunion occurred in 9 of 48 (19%) fractures following a high energy mechanism compared to 1 of 34 (3%) following a lower energy mechanism ($p = 0.038$). There was no significant difference in age between patients achieving union (median age 58) versus nonunion (median age 53) ($p=0.69$). Other patient characteristics such as pre-injury smoking status, diagnosis of diabetes, or injury characteristic of open versus closed fracture were also not significant

prognostic indicators for nonunion. The nonunion rate was 17% for open (4 of 24) and 10% for closed (6 of 58) fractures ($p = 0.484$). Nonunion occurred in 4 of 21 (19%) smokers versus 6 of 61 (10%) nonsmokers ($p = 0.270$) and 2 of 14 (14%) diabetic versus 8 of 68 (12%) nondiabetic patients ($p = 0.678$). The relationship of healing outcome to patient demographics and injury characteristics is summarized in Table 1.

*Predictive Accuracy of Cortical Bridging*

ROC analysis demonstrated that the predictive accuracy of radiographic criteria varied significantly. Assessing for any cortical bridging was most accurate in discriminating between eventual union and nonunion. Additionally, this criterion was accurate earlier than the more stringent criteria of bicortical or tricortical bridging given the prolonged time required to confirm bridging of multiple cortices (Figure 1).

*Any Cortical Bridging*

ROC analysis demonstrated that time to any cortical bridging was an excellent predictor of final healing with an area under the ROC curve of 0.92 ($p < 0.01$). It was also an earlier predictive marker compared to other criteria (Figure 2). The optimum postoperative time to evaluate radiographs based on this criterion was 4 months (accurate in 78 of 82, 95.1%). Bridging of any cortex within four months was noted in 74 fractures (n=6 unicortical, n=51 bicortical, n=13 tricortical, and n=4 quadricortical bridging). The postoperative radiographs of one such fracture are presented in Supplemental Digital Content 1 http://links.lww.com/BOT/A998, with unicortical bridging at 3 months, bicortical bridging at 8 months, and tricortical bridging at 13 months. Three of these 74 radiographically bridged

fractures were later diagnosed with nonunion based on implant failure and clinical symptoms (positive predictive value for union: 95.9%). Of the eight fractures lacking cortical bridging at four months, seven went on to nonunion (negative predictive value: 87.5%). Among fractures that united, the time to achieve any degree of cortical bridging was unaffected by patient factors and injury characteristics (Table 2).

*Bridging of Additional Cortices*

Criteria requiring bicortical or tricortical bridging were less predictive of the healing outcome with areas under the ROC curve of 0.85 ($p < 0.01$) and 0.76 ($p < 0.01$), respectively (Figure 3). Additionally, given the time required to bridge multiple cortices and the difficulty of visualizing all cortices with plate fixation in place, fewer fractures met these criteria early (Figure 1). The optimum postoperative times to evaluate radiographs based on these criteria were 6 months for bicortical bridging (accurate in 77 of 82, 93.9%) and 21 months for tricortical bridging (64 of 82, 78%).

*Timing of Radiographic Assessment: Effect on Predictive Accuracy*

The predictive accuracy of cortical bridging was highly dependent on the time of radiographic assessment and number of cortices required (Figure 2). Assessment for any cortical bridging at four months was accurate in predicting the healing outcome in 78 of 82 fractures (95.1%). Assessing for bridging of additional cortices was less predictive and required further postoperative delay to achieve this accuracy. Bicortical bridging required 6 months and tricortical bridging required 21 months postoperatively to achieve maximal predictive accuracy. Notably, three nonunions (3.6%) were miscategorized as appropriately healing fractures by both

unicortical and bicortical bridging. These were diagnosed as nonunions more than 12 months postoperatively based on signs, symptoms, and intraoperative findings despite apparent radiographic bridging of multiple cortices.

*Interobserver Reliability Varies by Radiographic Criteria Studied*

Interobserver reliability was assessed among three orthopaedic traumatologists for bridging of any cortex (kappa 0.73, 83% agreement), at least bicortical bridging (kappa 0.27, 45% agreement), and for at least tricortical bridging (kappa 0.5, 63% agreement). Assessing the interobserver reliability for the exact number of bridged cortices (0, 1, 2, 3, or 4) demonstrated a kappa coefficient of 0.24 correlating with 15% agreement. One or more cortices were obscured at the fracture site for the vast majority of radiographs. Of 191 radiographic evaluations, all four cortices were visible on only 23 (12%). A single cortex was obscured for 73 (38.2%), two cortices were obscured for 92 (48.2%) and all cortices were obscured for three (1.6%). Any cortex hidden from assessment on postoperative radiographs was assumed not to be bridged.

**Discussion**

In this series of 82 patients treated with lateral plating of supracondylar femur fractures, the treating traumatologist declared union without subsequent intervention in 6 patients (7%) at four months, 16 (20%) at six months, 32 (39%) at nine months, 45 (55%) at 12 months, and 72 (88%) at final follow up. Forty of the 72 unions (56%) required more than nine months of evaluation to be declared united. However, all but one of these slowly healing fractures had achieved radiographically identified unicortical bridging by four months. The single fracture without visible bridging at four months that eventually healed without intervention had

obscuration of multiple cortices by the fixation on early radiographs and bridging was not identified until 6 months postoperatively.

The overall nonunion rate was 12% (10 of 82 fractures), which falls within the range previously reported literature.[7-11, 13, 15, 17-19] The median time to diagnosis of nonunion was eight months and followed implant failure in five of ten cases. These results are consistent with previous literature reporting that 50% of distal femoral nonunions are diagnosed late and that the reported nonunion rate is strongly associated with duration of follow-up.[8]

In our analysis, seven of ten nonunions failed to bridge a single cortex postoperatively. The three nonunions that demonstrated radiographic cortical bridging had all shown multiple cortices to be radiographically bridged. These hypertrophic nonunions were all diagnosed based on clinical signs and symptoms. All three of the diagnoses were confirmed intraoperatively. Fibrous nonunion of distal femur fractures is particularly difficult to diagnosis on plain radiography, as plate fixation may obscure fibrous nonunion sites within incompletely bridged fractures.

We report that assessing for any cortical bridging as early as four months postoperatively accurately predicted union versus nonunion for 95.1% of supracondylar femur fractures in this series. Any cortical bridging was generally indicative of an adequate early healing response and predicted union in 71 out of 74 cases, while lack of bridging callus at four months was associated with nonunion in seven of eight cases. The high predictive accuracy of this assessment is explained by the consistent timing of cortical bridging for fractures achieving union (Table 2). The area under the ROC curve for this criterion (0.92) is similar to that reported for other clinically useful criteria in orthopaedic surgery, and this is consistent with it being an excellent

predictor of the final healing outcome (an area under the curve of 1.0 would be a perfect prediction).[24, 25, 27]

The accuracy of radiographic assessment in predicting fracture healing has been reported to be as low as 50%.[18] In this study, some degree of cortical bridging occurred in the first four postoperative months for all but one fracture achieving union, thus potentially allowing accurate predictions to be made for nearly all fractures prior to implant failures. Bicortical and tricortical bridging were less accurate in predicting the healing outcome. Therefore, simply requiring more cortices to be bridged does not improve predictive accuracy. This is consistent with recently published findings regarding radiographic assessment of cortical bridging in tibial shaft fractures.[28] That study demonstrated that for tibia fractures treated with intramedullary nailing, cortical bridging at four months predicted the healing outcome of 99% of the fractures. In the current study, fractures treated with plate fixation are assessed in a similar manner. Plate fixation obscures cortices on radiographs, and in our series this was associated with a slightly lower predictive accuracy and reliability than previously demonstrated for nailed tibial shaft fractures. However, the relative findings remain the same.

Bridging callus is a relatively reliable radiographic finding that is predictive of the mechanical strength of healing bone.[20-24] Despite the use of bicortical and tricortical bridging as radiographic criteria to confirm a fracture is healed, there is little evidence regarding the degree of cortical bridging which constitutes “normal healing” over time.[29-31] We found that any cortical bridging was the most reliable radiographic criterion studied (kappa 0.73), comparing favorably with previously studied radiographic assessments and surgeons’ impressions of healing.[24, 27] In contrast, the criteria of bicortical (kappa 0.27) and tricortical (kappa 0.5) bridging were relatively unreliable. The basis for the low reliability of these more stringent criteria is likely multifactorial.

Requiring agreement on the specific number of cortices bridged is inherently less reliable than asking for agreement on whether any cortical bridging exists. Additionally, lateral plate fixation obscures cortical detail (multiple cortices obscured on approximately 50% of radiographs).

Independent of their poor reliability, the more stringent criteria were also relatively inaccurate in predicting union based on early radiographs given the long time many distal femur fractures required to bridge multiple cortices. The accuracy of these assessments improved over time, but they remained inaccurate until after many nonunions were already diagnosed by implant failure or through clinical evaluation. Thus, more stringent criteria are of poor clinical utility in predicting the healing outcome for this fracture type and construct.

Employing the criterion of any cortical bridging at four months for clinical decision-making in our case series would have resulted in the earlier treatment of seven (70%) of the nonunions (prior to any implant failures) and would have avoided unnecessary intervention for five fractures that healed with further observation alone, but had limited cortical bridging (unicortical bridging only) at four months. This criterion was predictive regardless of the presence of other risk factors for nonunion including smoking and diabetes. Additionally, the nonunions that were missed by this criterion were also missed by the more stringent criteria studied, as these two fractures bridged multiple cortices radiographically and their ultimate diagnosis required a combination of clinical examination and three-dimensional imaging.

If instead patients had been strictly indicated for secondary interventions based on lack of bicortical or tricortical bridging, significant overtreatment likely would have occurred. For example, indicating patients for bone grafting at six months postoperatively due to a lack of tricortical bridging would have resulted in treating seven true nonunions and fourteen other fractures that healed with observation alone. Using a 6-month time point and bicortical bridging

criterion would have resulted in surgery for seven true nonunions and two fractures that healed with observation alone.

Limitations of this study include its retrospective design. It is possible that fractures appearing both clinically and radiographically healed at final follow-up may have presented to another institution with late construct failure at a later date. Late construct failure has been a concern with distal femur fractures in previous studies. We attempted to mitigate this potential issue by being quite strict in our definition of union, however, future investigation should include external, prospective validation of these findings. Although our results show only mechanism of injury to be a significant prognostic indicator for nonunion, the direct cause(s) of the nonunions are beyond the scope and power of this study, and the study was not specifically powered for that assessment. A strength of this study was that it was not designed with the assumption that a specific criterion was correct. Instead, it was appropriately powered to employ an analytic method (ROC curve analysis) to determine the relative predictive accuracy of each criterion and to ascertain the time points at which each was most accurate.

Assessing radiographic cortical bridging four months after lateral plating of supracondylar femur fractures provides particularly useful data to the treating surgeon. However, plate fixation partially obscures the cortices at the fracture site and further research is warranted to improve the assessment of healing in the setting of plate fixation. Additional oblique views or three-dimensional imaging may be useful in cases for which standard radiographic views are indeterminate. Given that any radiographic bridging within four months has been shown to be highly predictive of final healing for tibial shaft fractures and supracondylar femur fractures, further research into the utility of this assessment is warranted.

**Conclusions:**

Radiographic criteria are predictive of the final healing outcome of supracondylar femur fractures treated with locking plate fixation. The predictive accuracy varies by the criteria studied and the time of assessment. Assessing for any cortical bridging is more accurate and accurate earlier after surgery (95.1% accuracy at four months postoperatively), then more stringent criteria requiring bicortical or tricortical bridging. Any cortical bridging also demonstrated the best interobserver reliability (kappa 0.73) relative to bicortical (kappa 0.27) or tricortical bridging (kappa 0.5).



**References**

1. Martinet O, Cordey J, Harder Y, et al. The epidemiology of fractures of the distal femur. *Injury*. 2000;31 Suppl 3:C62-63.

2. Court-Brown CM, Caesar B. Epidemiology of adult fractures: A review. *Injury*. 2006;37:691-697.

3. Kubiak EN, Fulkerson E, Strauss E, et al. The evolution of locked plates. *J Bone Joint Surg Am*. 2006;88 Suppl 4:189-200.

4. Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. *J Bone Joint Surg Br*. 2002;84:1093-1110.

5. Button G, Wolinsky P, Hak D. Failure of less invasive stabilization system plates in the distal femur: a report of four cases. *J Orthop Trauma*. 2004;18:565-570.

6. Egol KA, Kubiak EN, Fulkerson E, et al. Biomechanics of locked plates and screws. *J Orthop Trauma*. 2004;18:488-493.

7. Fankhauser F, Gruber G, Schippinger G, et al. Minimal-invasive treatment of distal femoral fractures with the LISS (Less Invasive Stabilization System): a prospective study of 30 fractures with a follow up of 20 months. *Acta Orthop Scand*. 2004;75:56-60.

8. Henderson CE, Kuhl LL, Fitzpatrick DC, et al. Locking plates for distal femur fractures: is there a problem with fracture healing? *J Orthop Trauma*. 2011;25 Suppl 1:S8-14.

9. Herrera DA, Kregor PJ, Cole PA, et al. Treatment of acute distal femur fractures above a total knee arthroplasty: systematic review of 415 cases (1981-2006). *Acta Orthop*. 2008;79:22-27.

10. Lujan TJ, Henderson CE, Madey SM, et al. Locked plating of distal femur fractures leads to inconsistent and asymmetric callus formation. *J Orthop Trauma*. 2010;24:156-162.

11. Ricci WM, Loftus T, Cox C, et al. Locked plates combined with minimally invasive insertion technique for the treatment of periprosthetic supracondylar femur fractures above a total knee arthroplasty. *J Orthop Trauma*. 2006;20:190-196.

12. Ring D, Kloen P, Kadzielski J, et al. Locking compression plates for osteoporotic nonunions of the diaphyseal humerus. *Clin Orthop Relat Res*. 2004:50-54.

13. Schutz M, Muller M, Regazzoni P, et al. Use of the less invasive stabilization system (LISS) in patients with distal femoral (AO33) fractures: a prospective multicenter study. *Arch Orthop Trauma Surg*. 2005;125:102-108.

14. Sommer C, Gautier E, Muller M, et al. First clinical results of the Locking Compression Plate (LCP). *Injury*. 2003;34 Suppl 2:B43-54.

15. Syed AA, Agarwal M, Giannoudis PV, et al. Distal femoral fractures: long-term outcome following stabilisation with the LISS. *Injury*. 2004;35:599-607.

16. Uhthoff HK, Poitras P, Backman DS. Internal plate fixation of fractures: short history and recent developments. *J Orthop Sci*. 2006;11:118-126.

17. Weight M, Collinge C. Early results of the less invasive stabilization system for mechanically unstable fractures of the distal femur (AO/OTA types A2, A3, C2, and C3). *J Orthop Trauma*. 2004;18:503-508.

18. Wong MK, Leung F, Chow SP. Treatment of distal femoral fractures in the elderly using a less-invasive plating technique. *Int Orthop*. 2005;29:117-120.

19. Henderson CE, Bottlang M, Marsh JL, et al. Does locked plating of periprosthetic supracondylar femur fractures promote bone healing by callus formation? Two cases with opposite outcomes. *Iowa Orthopaedic Journal*. 2009;28:73-75.

20. Hammer RR, Hammerby S, Lindholm B. Accuracy of radiologic assessment of tibial shaft fracture union in humans. *Clin Orthop Relat Res*. 1985:233-238.

21. Kooistra BW, Dijkman BG, Busse JW, et al. The radiographic union scale in tibial fractures: reliability and validity. *J Orthop Trauma*. 2010;24 Suppl 1:S81-86.

22. McClelland D, Thomas PB, Bancroft G, et al. Fracture healing assessment comparing stiffness measurements using radiographs. *Clin Orthop Relat Res*. 2007;457:214-219.

23. Panjabi MM, Walter SD, Karuda M, et al. Correlations of radiographic analysis of healing fractures with strength: a statistical analysis of experimental osteotomies. *J Orthop Res*. 1985;3:212-218.

24. Whelan DB, Bhandari M, McKee MD, et al. Interobserver and intraobserver variation in the assessment of the healing of tibial fractures after intramedullary fixation. *J Bone Joint Surg Br*. 2002;84:15-18.

25. Whelan DB, Bhandari M, Stephen D, et al. Development of the radiographic union score for tibial fractures for the assessment of tibial fracture healing after intramedullary fixation. *J Trauma*. 2010;68:629-632.

26. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma*. 2007;21:S1-133.

27. Lack WD, Fredericks D, Petersen E, et al. Effect of aspirin on bone healing in a rabbit ulnar osteotomy model. *J Bone Joint Surg Am*. 2013;95:488-496.

28. Lack WD, Starman JS, Seymour R, et al. Any Cortical Bridging Predicts Healing of Tibial Shaft Fractures. *J Bone Joint Surg Am*. 2014;96:1066-1072.

29. Govender S, Csimma C, Genant HK, et al. Recombinant human bone morphogenetic protein-2 for treatment of open tibial fractures: a prospective, controlled, randomized study of four hundred and fifty patients. *J Bone Joint Surg Am*. 2002;84-A:2123-2134.

30. Hernigou P, Poignard A, Beaujean F, et al. Percutaneous autologous bone-marrow grafting for nonunions. Influence of the number and concentration of progenitor cells. *J Bone Joint Surg Am*. 2005;87:1430-1437.

31. Keating JF, O'Brien PJ, Blachut PA, et al. Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft. A prospective, randomized study. *J Bone Joint Surg Am*. 1997;79:334-341.

**Figure Legends:**

**Figure 1.** Time (months) to achieve various degrees of cortical bridging for fractures that achieved union.

**Figure 2.** Predictive accuracy of cortical bridging criteria and final healing outcome. The criterion of any cortical bridging achieved 95.1% accuracy at only four months postoperatively.

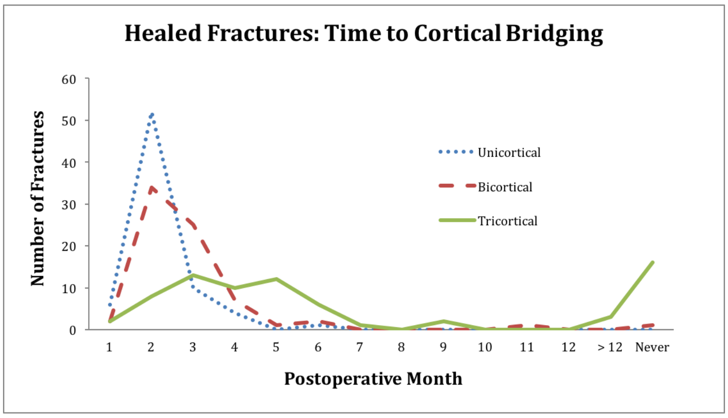
**Figure 3**. ROC curves demonstrating that accuracy in predicting the final healing outcome varied by the criterion studied and the time of assessment. Any cortical bridging was the most predictive criterion with an area under the curve (AUC) of 0.92.

**Table 1.** Summary of patient demographics and injury characteristics of those achieving union versus nonunion in fracture healing.

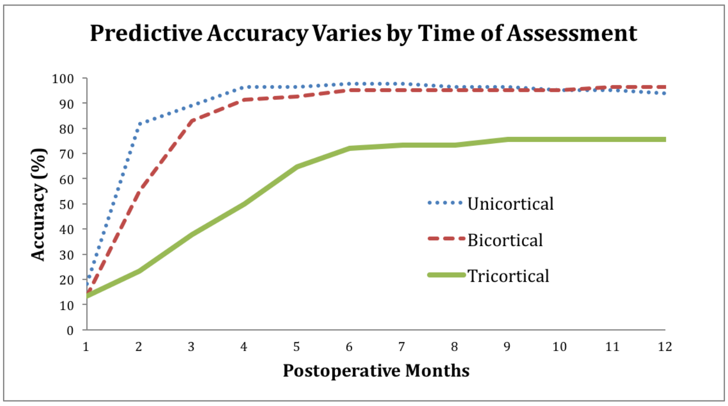
| **Patient/Injury Characteristics** | **Union** N = 72 | **Non-Union** N = 10 | ***p-value*** |
|---|---|---|---|
| **Age (median)** | 58 years | 53 years | 0.69 |
| **Energy** | | | 0.04 |
| High | 39 (81%) | 9 (19%) | |
| Low | 33 (97%) | 1 (3%) | |
| **Smoker** | | | 0.27 |
| Yes | 17 (81%) | 4 (19%) | |
| No | 55 (90%) | 6 (10%) | |
| **Diabetes** | | | 0.68 |
| Yes | 12 (86%) | 2 (14%) | |
| No | 60 (88%) | 8 (12%) | |
| **Fracture** | | | 0.48 |
| Closed Fracture | 52 (90%) | 6 (11%) | |
| Open Fracture | 20 (83%) | 4 (16%) | |

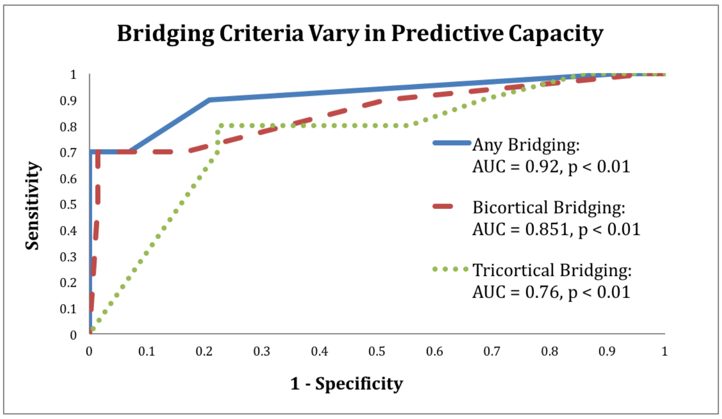
**Table 2.** Summary of time to cortical bridging (in months) for fractures achieving union based on patient and injury characteristics. Some degree of cortical bridging was radiographically visible within four months for 71 of 72 fractures achieving union. Patient and injury characteristics did not affect time required to achieve cortical bridging.

| | **Valid N** | **Median months to any bridging (range)** | ***p*-value** |
|---|---|---|---|
| **Overall** | 72 | 1.75 (0.50-5.75) | -- |
| **Energy** | 72 | | 0.27 |
| Low | 33 | 1.75 (0.50-5.75) | |
| High | 39 | 1.75 (0.75-3.50) | |
| **Smoker** | 72 | | 0.64 |
| No | 55 | 1.75 (0.50-5.75) | |
| Yes | 17 | 2.00 (1.00-3.00) | |
| **Diabetes** | 72 | | 0.06 |
| No | 60 | 1.75 (0.75-5.75) | |
| Yes | 12 | 1.70 (0.50-2.00) | |
| **Fracture** | 72 | | 0.66 |
| Closed | 52 | 1.75 (0.50-5.75) | |
| Open | 20 | 2.00 (0.75-3.50) | |



Healed Fractures: Time to Cortical Bridging
Number of Fractures
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
> 12
Never
Postoperative Month
Unicortical
Bicortical
Tricortical


Predictive Accuracy Varies by Time of Assessment
Accuracy (%)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Postoperative Months
Unicortical
Bicortical
Tricortical


Bridging Criteria Vary in Predictive Capacity
Sensitivity
1 - Specificity
Any Bridging:
AUC = 0.92, p < 0.01
Bicortical Bridging:
AUC = 0.851, p < 0.01
Tricortical Bridging:
AUC = 0.76, p < 0.01
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1