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Low-Cost Surveillance for Lower Extremity Fracture Union After Intramedullary Nailing – Experience on 80 Sign Patients by a Philippine Trauma Center

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Abstract: There is a need to come up with low-cost strategies for assessing fracture union following surgical treatment in developing countries. We aimed to develop one by determining the optimal surveillance schedule taking into account associated factors and the diagnostic performance of the Squat & Smile (S & S) test. A total of 80 patients with lower extremity fracture treated with the SIGN nail were followed for at least 8 months. Time to fracture union was calculated using the Radiographic Union Scale in Tibial Fractures (RUST) scoring and variables were analyzed for association with fracture union. Forty-eight patients performed additional S & S test. Sensitivity, specificity, positive and negative predictive values, and the diagnostic accuracy of S & S test were assessed. Ten (12.5%) of 80 patients developed nonunion, and the presence of superficial infection (28.5 ± 5.6 weeks vs 17.2 ± 1.2 weeks, p=.01) and pain on weight-bearing (29.6 ± 2.2 weeks vs 16.8 ± 1.2 weeks, p < .001) were associated factors. Cumulative incidence at 16 weeks was 59% (58% to 60%). The S & S test had high Sn (90%) and Sp (100%) in diagnosing union. The NPV and PPV were 67% and 100%, respectively, with a diagnostic accuracy of 92%. We concluded that S & S test may reliably detect fracture union by fourth month after surgery, while closer follow-up is likely needed for patients developing superficial infection or pain on weight-bearing.

Keywords: RUST, Squat and Smile Test, SIGN, Trauma, Fracture

1. Introduction

Trauma has been recognized as a global epidemic, with majority of nonfatal injuries being orthopaedic in nature and mostly affecting those living in developing countries with limited access to health care [1, 2]. Considering out-of-pocket payments as the primary source of health financing in low-and-middle income countries like the Philippines, the cost of an implant is one significant obstacle to fracture care delivery [3]. As such, lower extremity injuries contribute to the cycle of poverty, and the economic burden becomes unbearable when the total expenditure incurred by patients is higher than the minimum wage [3, 4]. A nonprofit organization, the SIGN Fracture Care International (SIGN), has developed a US Food and Drug Agency-approved intramedullary (IM) prosthesis called the SIGN nail [5]. The SIGN nails have shown good outcomes in clinical series and are donated to affiliated hospitals in developing countries where orthopaedic surgeons can thus treat long-bone fractures without much concern for implant-related costs [5]. IM nailing remains the standard of care for closed diaphyseal fractures of the lower extremity, although excellent fracture union may be expected only when performed in the acute setting [6, 7]. Provision of implants is seen as a rate-limiting step in fracture care systems of many developing countries, with one Philippine study documenting an average interval of thirty-five days from inpatient admission to surgery using non-SIGN nails [3]. By this time, fractures have already developed exuberant callus, making the surgery more difficult to perform and at risk for complications [8]. Surveillance for radiographic union must be an essential component of fracture care in low-resource settings, for nonunion entails high complexity of management making it extremely costly to treat [9, 10]. The Radiographic Union Scale in Tibial Fractures (RUST) scoring is one applicable system for quantifying fracture consolidation on radiographs after IM nailing, and has been demonstrated to be a reliable and repeatable outcome measure for assessing fracture healing [11-13].

But dependence of surveillance on serial radiographs must entail expenses, which may discourage follow-up among patients coming from poor communities. The Squat and Smile (S & S) test has been developed by the SIGN to monitor fracture union following treatment using SIGN nails, ascertaining bone healing by capability of the patient to perform deep bending of both knees with a facial expression showing no pain [14]. Subsequent validations of the proxy only emphasize the need to come up with low-cost strategies for assessing fracture union in low- resource settings [15, 16]. Moreover, literature assessing reliability of S & S test in predicting fracture union is scarce [14-16]. The present paper therefore aimed to develop a low-cost surveillance strategy for lower extremity fracture union that must be useful in developing countries like the Philippines, by: 1) determining the optimal surveillance schedule following IM nailing taking into account factors associated with lower extremity fracture union, and 2) assessing diagnostic performance of the S & S test using the RUST scoring as standard.

2. Materials and Methods

A review of the SIGN Online Surgical Database [17] identified 128 patients with lower extremity diaphyseal fractures who underwent IM nailing in a tertiary trauma center in the Philippines from January 1, 2018 to February 28, 2021. Institutional Ethics Review Board (IERB) approval was obtained. Among the 128 patients, 7 had multiple fractures while 4 had pathologic fractures caused by either tumor or infection. Of the remaining 117 patients, 37 with insufficient radiographs (less than three time points) or less than 8 months of radiographic surveillance were excluded, which left 80 patients for analysis. Median follow-up after surgery is 12 months (range, 8 to 32 months).

The standard SIGN technique of IM nailing was performed for all patients [18]. Early mobilization and range of motion exercises were encouraged following the operation, although fracture type and stability of fixation influenced whether a patient was allowed full, partial, or no weight- bearing. Patients were sent home when there are no signs of deep infection or hematoma formation in the surgical site and serum hemoglobin has been optimized. Wounds were serially inspected after surgery in conjunction with fracture nonunion surveillance. Patient demographics, management, and outcome were retrospectively obtained from hospital charts upon approval of our study protocol by the IERB. Radiographs of the patient cohort were reviewed using the institution's radiology information system (OsiriX), and all postoperative and subsequent follow-up radiographs were evaluated using the RUST. The time taken in weeks for a fracture to unite, defined as total RUST score of at least 10 (range, 10 to 12) [19], was recorded for each patient. Diagnosis of nonunion was made when total RUST score was at most 8 (range, 4 to 8) following 8 postoperative months or at the time of last follow-up [19, 20]. If the time between the united and prior radiographs were longer than six weeks, we estimated time to healing by taking the average between these two time points [19]. We then cross checked using the SIGN Online Surgical Database and identified 48 patients from the study cohort with S & S photos. We considered the S & S test to be positive for squatting ability and thus, fracture union, when photograph shows level of buttocks lower than both knees on lateral view with the patient unassisted and smiling [14].

Cumulative incidence functions were used to estimate the cumulative incidence and 95% confidence interval. Time to fracture union was calculated from the time of operation, and patients who developed nonunion were censored at the time of last follow-up. Event-free survival (EFS) was estimated using Kaplan-Meier survival curves, and the Log-rank test was performed to identify factors associated with fracture nonunion. We evaluated performance of the S & S test in diagnosing fracture union using the RUST as gold standard, and from the 2x2 table, specificity (Sp), sensitivity (Sn), positive (PPV) and negative predictive values (NPV), and diagnostic accuracy of the S & S test were calculated [14]. Statistical analyses were performed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA), with a two-tailed p-value of $< .05$ considered significant.

3. Results

Table 1. *Patient Characteristics.*

	N=80
Age in years*	34 (17 to 78)
>40 years**	57 (71)
<40 years**	23 (29)
Gender	
Men**	71 (89)
Women**	9 (11)
Bone involvement	
Femur**	49 (61)
Tibia**	31 (39)
Fracture configuration	
Simple**	56 (70)
Multi-fragmentary**	24 (30)
Fracture classification	
Closed**	58 (72)
Open**	22 (28)
Reduction method	
Closed**	16 (20)
Open**	64 (80)
Presence of deep infection	
Yes**	8 (10)
No**	72 (90)
Pain on weight-bearing**	
Yes**	7 (9)
No**	73 (91)

*Presented as mean with range in parentheses

**Presented as number with percentage in parentheses.

Baseline characteristics are described in Table 1. There were 71 (89%) men and 9 (11%) women, with mean age of 34 years (range, 17 to 78 years). Forty-nine (49, 61%) fractures were of the femur, while 31 (39%) involved the tibia. Majority of the fractures were simple (56, or 70%), and closed (58, or 72%). Most (64, or 80%) of the patients underwent open reduction of their fracture, while 16 (20%) had closed reduction. Seventy-two (72, 90%) patients did not develop superficial infection, and majority (73, or 91%) had no pain on weight-bearing.

Ten (12.5%) of the 80 patients developed nonunion, and the mean interval from IM nailing to the detection of fracture union was 18 weeks (range, 12 to 31 weeks). Four cases of femoral nonunion and 1 case of tibial nonunion resolved following intervention (Table 2). Four were lost to follow up after diagnosis of oligotrophic nonunion, while 1 patient (Case 4) expired due to medical comorbidities. Thirty-five (44%) femoral fractures and 13 (16%) tibial fractures united within 18 weeks of surgery, and the cumulative incidence at 12, 16, and 20 weeks were 41% (40% to 42%), 59% (58% to 60%), and 66% (65% to 67%), respectively (Figure 1).

Table 2. *Postoperative Nonunions.*

Case No.	Age/Sex	Bone involved	Nonunion	Treatment	Outcome
Case 3	25/M	Femur	Aseptic	-	-
Case 4	56/M	Tibia	Aseptic	-	-
Case 36	19/M	Femur	Septic	Debridement, fibular strut graft, antibiotics	Resolved
Case 37	31/M	Tibia	Aseptic	-	-
Case 41	38/M	Tibia	Septic	-	-
Case 51	26/M	Femur	Aseptic	-	-
Case 54	28/F	Femur	Aseptic	Dynamization and bone grafting	Resolved
Case 58	28/M	Tibia	Septic	Local debridement/oral antibiotics	Resolved
Case 65	29/M	Femur	Septic	Local debridement/oral antibiotics	Resolved
Case 66	50/M	Femur	Septic	Debridement, external fixation, antibiotics	Resolved

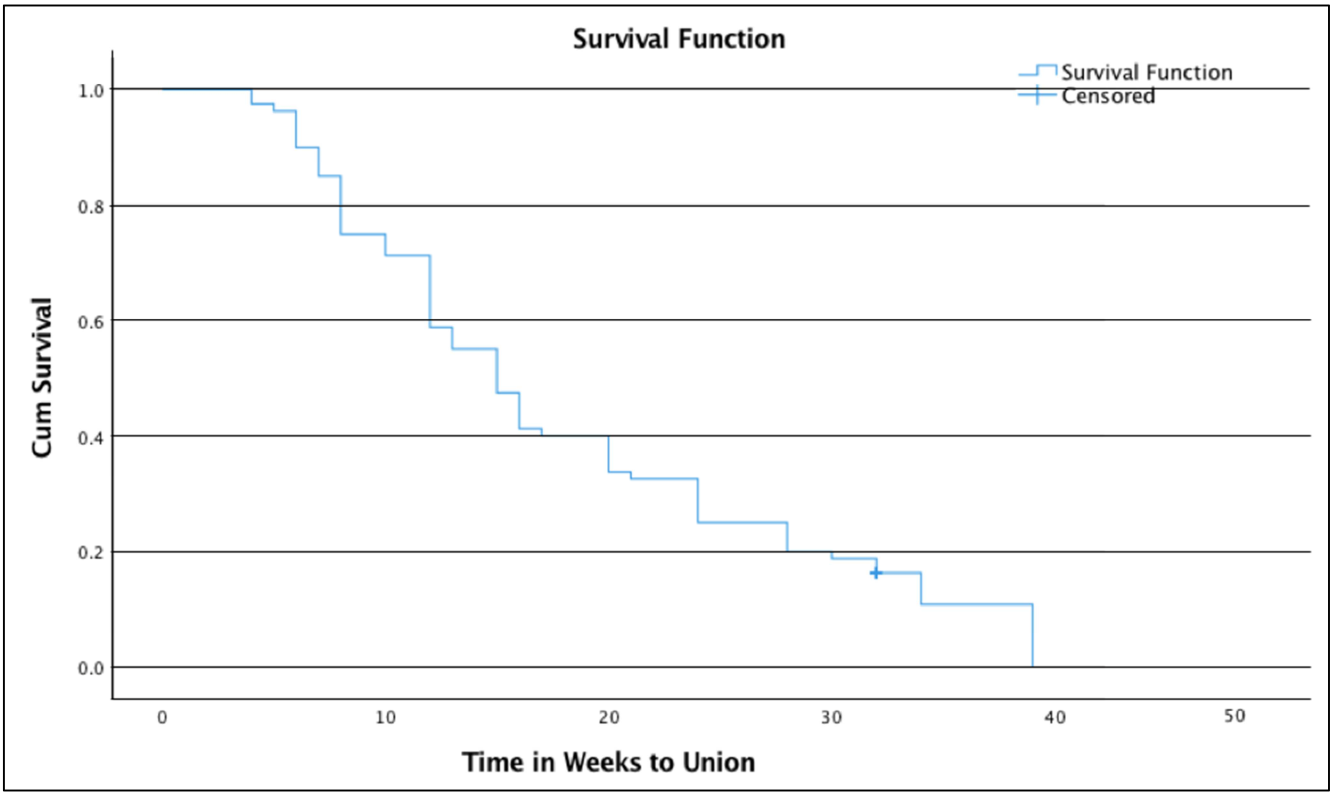

Figure 1. *Cumulative Incidence of Time in Weeks to Fracture Union.*

On univariate analysis of possible factors related to nonunion, patients who developed superficial infection (28.5 ± 5.6 weeks vs 17.2 ± 1.2 weeks, p=.01), and had pain on weight-bearing (29.6 ± 2.2 weeks vs 16.8 ± 1.2 weeks, p < .001) had significantly longer EFS, i.e., longer fracture healing period, than patients without infection and pain on weight-bearing (Table 3). Patient age, gender, bone involvement, fracture configuration, fracture classification, and reduction method were not associated with development of nonunion.

Table 3. *Univariate Analysis of Data.*

	Total (n)	Union (n)	Event-free survival (weeks)	95% CI	P-value (log-rank)
Age					
>40 years	23	21	32	12.3-21.5	0.408
<40 years	57	49	32	16.2-21.9	
Gender					
Men	71	62	32	16.4-21.5	0.125
Women	9	8	15	7.9-17.7	
Bone involvement					
Femur	49	43	32	13.4-19.6	0.133
Tibia	31	27	32	17.6-25	
Fracture configuration					
Simple	56	49	32	14.8-20.8	0.563
Multi-fragmentary	24	21	32	15.6-23.6	
Fracture classification					
Closed	58	51	32	14.6-20.6	0.467
Open	22	19	28	16.3-22.6	
Reduction method					
Closed	16	12	28	15.5-24.4	0.24
Open	64	58	32	15-20.2	
Presence of deep infection					
Yes	8	4	39	14.9-19.6	0.01
No	72	66	32	17.6-39.4	
Pain on weight-bearing					
Yes	7	1	39	25.2-34	< .001
No	73	69	32	14.6-19.1	

Table 4. *Multivariate Analysis of Data.*

	Relative risk	95% confidence interval	P-value
Deep infection	0.54	0.18 to 1.54	.247
Pain on weight-bearing	10.5	1.41 to 76.9	.022

Forty-eight (48) of the 80 patients had S & S photos in addition to radiographic surveillance. All (100%) positive S & S tests were confirmed unions by the RUST, while 8 (67%) of 12 negative S & S tests were confirmed nonunions by the RUST (Table 5). Therefore, S & S test was highly sensitive (90%) and specific (100%) in diagnosing fracture union, with NPV and PPV of 67% and 100%, respectively, and accuracy of 92% (44/48).

Table 5. *Diagnostic Performance of Squat and Smile test.*

	RUST -positive	RUST -negative	
S & S -positive	36	0	PPV: 100%
S & S -negative	4	8	NPV: 67%
	Sn: 90%	Sp: 100%	

4. Discussion

Fracture treatment in developing countries is limited by the provision of orthopaedic implants [3], which, when delayed, could result to perioperative complications [8]. Radiographic surveillance is therefore essential to avoid the complex and costly management of fracture nonunion [9, 10]. However, dependence on serial radiographs entails costs that can limit follow- up among patients coming from poor communities. Low-cost strategies for surveillance following fracture treatment are therefore needed in low-resource settings. The present paper aimed to develop a low-cost surveillance strategy by analyzing the incidence and timing of fracture union with regard to associated factors, and validating the S & S test as screening tool.

The present study is not without limitations. First, we did not include delayed union as separate endpoint for the analyses. Leow et al. [19] speculated that delayed union is a distinct healing type and not just demonstrating slower healing. However, they noted the histogram of healing times illustrating a single peak without a separate second peak, emphasizing that delayed union is not a distinct entity but a subset of the normal healing process. Second, selection bias may be unavoidable considering our analysis being retrospective in nature. But with majority of our patients aged less than 50 years, our study found a predominance of males, similar to Meling et al.'s [21] four-year prospective series of long bone fractures in a Norwegian population. Third, surveillance schedule was not standardized, as only 48 patients were able to send photos for the S & S assessment. We recognize the limitation in our evaluation of the S & S test's diagnostic performance, which may have resulted in overestimation by the present analysis. Traditional clinical research using standard follow up is extraordinarily difficult in low-resource settings, where pursuing regular follow-up can be a financial burden to many patients [5]. Similar to experiences of Young et al. [22], patients treated in our institution most commonly see us for removal of wound sutures or development of a complication but hardly for standard postoperative surveillance. Fourth, multi-institutional studies involving larger cohorts may be necessary to address the relatively small number of patients we included. Lastly, identification of more variables affecting nonunion could have provided a more detailed and effective surveillance strategy following fracture treatment.

The mean interval between IM nailing and fracture union in the present study was 18 weeks, which is similar to those of other series with mean interval ranging from 16 to 32 weeks [19, 23-26]. In addition, 59% of the fracture cohort achieved union within 4 months of surgery. This finding must be in line with previous studies that reported on the timing of fracture union after operative treatment. In a series of 17 patients with tibial fracture treated by IM nailing, 53% demonstrated radiographic union after 3 months that improved to 80% by the sixth postoperative month [23]. In another study, 121 (75%) of 157 tibial fractures demonstrated radiographic union in less than 6 months following IM nailing [25]. Moreover, Leow et al. found tibial fracture healing being considerably longer than 12 weeks, with 84% of patients expected to achieve bone healing by 6 months [19]. Taken together, surveillance for lower extremity fracture union is most likely to be effective by the fourth month after IM nailing.

The proportion of patients with lower extremity nonunion in the present study was 12.5%, which falls in the reported range of 2.8% to 23% [20, 26, 27]. Stratification of patients according to factors associated with nonunion is essential to provide effective surveillance strategy. In agreement with our findings, superficial infection has been found an independent predictor associated with nonunion following intramedullary nailing [26]. Makaram et al. suggested that superficial wound infection may conceal a deeper infection, while there could also be overlap between factors that predispose to superficial infection and those that increase nonunion risk [26]. Likewise, pain has been consistently reported to result from long-bone nonunion after fracture treatment [28-30]. Although high-energy mechanisms and open tibial fractures were commonly found to confer increased nonunion risk [26, 31], the present study did not identify significant association between open fracture, multi-fragmentary configuration or tibial involvement, and progression to nonunion. Similarly, age, gender, and reduction method were not found to be associated with fracture nonunion. Wu et al., in a series of 152 patients with femoral shaft fracture treated by IM nailing, found that the RUST scores were not significantly different between the nonunion and union groups at 3 postoperative months but became significantly lower in the nonunion group at 6 months following surgery, suggesting that nonunion may be predicted between 3 and 6 months after the operation [32]. We therefore strategized to consider aggressive radiographic follow-up on patients presenting with superficial infection or pain on weight-bearing at 4 months after lower extremity fracture surgery.

The S & S test provides an indispensable proxy for lower extremity fracture assessment in developing countries with limited radiographic imaging resources because it must be locally relevant and easy to administer [14, 16]. Using the RUST as gold standard, Maharjan et al. found the S & S test to be more specific (82%) than sensitive (64%) in predicting fracture healing [15]. Similarly, Alves et al. found higher specificity (85-91%) than sensitivity (11-17%) for the S & S test in their series [14]. The present study also found the test to be specific and thus, deem the assessment to be potentially reliable for predicting lower extremity fracture healing after IM nailing. Although Wu et al. suggested strict binary assessment of squat depth and the need for support for higher specificity (95% and 97%, respectively) [16], our use of the S & S test for purposes of the present study must be similarly validated by emphasis on squatting ability showing no need for support and the level of patient's buttocks below both knees [14]. An advantage of the S & S test rests on the assessment being performed remotely by either mobile telephone or text messaging [16], and this must be decisive in archipelagic countries like the Philippines where treatment centers are concentrated in the highly-urbanized areas [33]. Moreover, the S & S test's pertinence for teleconsultation must serve proper surveillance needed during times of isolation in the present COVID-19 era [33].

5. Conclusion

In conclusion, the Squat & Smile test could be a potential low-cost surveillance method for reliably detecting lower extremity fracture union especially after 4 months from IM nailing. However, closer follow-up with radiographic surveillance seems necessary for patients developing superficial infection or pain on weight-bearing. This clinical tool may be used by surgeons in monitoring the healing progress of patients that have logistical difficulties in complying with serial radiographic monitoring for fracture union. It is particularly beneficial in the surveillance of union for patients residing in remote areas and those affected by the restrictions of the pandemic.

Conflict of Interest Statement

All the authors do not have any possible conflicts of interest.

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