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Research Article

Association of Smoking, Nutritional Status, and Socioeconomic Factors with Radiographic Evidence of Delayed Fracture Healing

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ABSTRACT

Background: Fracture healing is influenced by a complex interaction of biological, behavioral, nutritional, and socioeconomic factors. Other factors such as smoking, which may negatively affect vascularity and osteogenesis, and malnutrition or socioeconomic disadvantage, which may negatively impact on the physiologic processes involved in bone repair, can also adversely affect the healing of fractures.

Objective: To determine the association of smoking, nutritional status, and socioeconomic factors with radiographic evidence of delayed fracture healing.

Methods: This analytical cross-sectional study was conducted at the Rawal Institute of Health Sciences from January 2025 to June 2025. Using non-probability consecutive sampling, a total of 86 cases of adult fractures were included in the study based on the patients' radiographs. Demographic data, smoking habits, nutritional indicators, serum albumin, hemoglobin level, socio-economic status, fracture characteristics, and radiographic healing were obtained. The healing of fractures was evaluated by serial roentgenograms by the methods of callus formation, formation of the bone line, persistence of the fracture line and overall progress toward healing. Chi-square or Fisher's exact test was used for analysis and multivariable binary logistic regression for associations. A p value <0.05 was deemed to be statistically significant.

Results: Delayed radiographic fracture healing was identified in 29 of 86 patients (33.7%). Delayed healing was more frequent among smokers than non-smokers (51.4% vs. 21.6%, p=0.004), among patients who were nutritionally at risk or malnourished compared with well-nourished patients (54.8% vs. 21.8%, p=0.006), and among those with low serum albumin compared with normal albumin levels (61.9% vs. 24.6%, p=0.003). Low socioeconomic status was also significantly associated with delayed healing (p=0.018). On multivariable analysis, current smoking (AOR=3.21, 95% CI: 1.22–8.43), poor nutritional status (AOR=2.84, 95% CI: 1.07–7.56), low serum albumin (AOR=3.47, 95% CI: 1.18–10.20), and low socioeconomic status (AOR=2.73, 95% CI: 1.01–7.39) remained independent predictors of delayed fracture healing.

Conclusion: Smoking, inadequate nutritional status, hypoalbuminemia, and socioeconomic disadvantage were significantly associated with delayed radiographic fracture healing. Early identification and modification of these risk factors may contribute to improved fracture-healing outcomes.

Keywords: Fracture Healing, Delayed Union, Smoking, Nutritional Status, Serum Albumin, Socioeconomic Status, Radiographic Healing.

INTRODUCTION

Fracture healing is a highly organized biological process, including inflammation, the formation of an angiogenic bed, soft callus formation, mineralization, and ultimate bone remodeling. While most fractures heal well with the right management, a small percentage of people have delayed healing or nonunion, leaving

them with a longer period of disability, more frequent hospital visits, more surgeries and higher health care costs. The rate of bone healing will also rely on systemic and behavioral factors that affect the metabolic needs and cellular activity of bone healing and the stability of the fracture treatment (1-3).

Smoking is an important potentially modifiable risk factor for poor bone healing. Nicotine, carbon monoxide, and many of the toxic chemicals in cigarette smoke can decrease peripheral blood flow, delivery of oxygen, inflammatory responses, and osteoblast function. Such effects may lead to disturbance of the vascularisation process and new bone formation at the fracture site. Smokers have thus been reported to take longer to heal and to have more delayed union and nonunion. This relationship may be heightened with increased amount and duration of smoking, and should be taken into account when assessing orthopedic issues and when evaluating outcomes after surgery (4, 5).

The nutrition status also plays a significant part in bone repair. The metabolic and protein needs are elevated during fracture healing, due to the need for sufficient energy and nutrients for collagen synthesis, callus formation, proliferation of cells, and deposition of mineral. All of these processes can be affected by protein-energy malnutrition, low levels of serum albumin, anemia, and deficiencies of essential vitamins and minerals, which are known to affect the biological ability of bone to heal. BMI is not a complete indicator of nutritional status as clinically important protein and micronutrient deficiencies can exist in all BMI ranges. Therefore, the use of a combination of anthropometric, clinical and biochemical markers could potentially be a better indicator of nutritional risk in fracture patients (6, 7).

Additionally, there are direct and indirect pathways by which socioeconomic factors could impact fracture recovery. People from disadvantaged backgrounds may face poorer access to healthy food, lack timely access to health services, have challenges attending for regular check-ups, have limited access to rehabilitation services and financial constraints in their ability to continue treatment. Additionally, there may be an interplay between socioeconomic disadvantage and smoking, inadequate nutrition, physically taxing work and low health literacy, all of which may have a negative impact on fracture healing. Behavioral, nutritional, and socioeconomic factors may be assessed in isolation, rather than in conjunction, in typical clinical investigations of fracture healing (8, 9).

There remains a need to assess these interrelated factors simultaneously in patients undergoing fracture follow-up, particularly in local clinical settings where socioeconomic disparities and nutritional limitations may substantially affect recovery. Identifying patients at increased risk of delayed union could facilitate early counseling, nutritional optimization, closer radiographic monitoring, and appropriate social support. Therefore, the present study was conducted to determine the association of smoking, nutritional status, and socioeconomic factors with radiographic evidence of delayed fracture healing among patients treated at the Rawal Institute of Health Sciences.

METHODOLOGY

This hospital-based analytical cross-sectional study was conducted at the Rawal Institute of Health Sciences from January 2025 to June 2025. The study was designed to evaluate the association of smoking, nutritional status, and socioeconomic factors with radiographic evidence of delayed fracture healing. A total of 86 patients with clinically and radiographically confirmed fractures were included. Patients of either sex, aged 18 years or above, who presented with fractures requiring follow-up and had available serial radiographs for assessment of healing were considered eligible. Patients with pathological fractures, malignancy-related fractures, severe metabolic bone disease, incomplete medical records, loss to follow-up, or radiographs unsuitable for assessment of fracture union were excluded from the study. Ethical approval was obtained from the Institutional Review Board/Ethics Committee of the Rawal Institute of Health Sciences before commencement of data collection, and written informed consent was obtained from all participants.

Participants were recruited using a non-probability consecutive sampling technique until the required sample size of 86 was achieved. Structured data collection form and patient interview were used to collect demographic and socioeconomic data. The data collected were age, sex, place of residence, educational level, occupation, monthly income of the house and socioeconomic classification. Socio-economic status was scored as low, middle and high based on predetermined socioeconomic variables that are relevant to the

local population. Anatomical location of fracture, mechanism of injuries, fracture type, fracture pattern, treatment modality, post-treatment infection were retrieved from hospital records and clinical examination.

Smoking exposure was measured in detail by obtaining information on current smoking status, years of smoking, mean number of cigarettes smoked per day, and pack-years. The main analysis was carried out by dividing patients into current smokers and non-smokers. Smokers were also split into smoking levels based on number of cigarettes smoked per day (light, moderate, heavy). Body weight, height were measured and body mass index (BMI) was calculated as body weight (kg) divided by height (m) squared. Standard BMI classification was used to categorize participants as underweight, normal weight, overweight, or obese. Lab data such as Hb and serum albumin were noted as additional indicators of nutrition as available. If serum albumin was < 3.5 g/dL, it was used as a cut-off for low. Assessment of overall nutritional status, based on clinical assessment, BMI and available biochemical indicators, was classified as either well nourished, nutritionally at risk or malnourished.

The radiographic healing was assessed by serial plain radiographs taken at routine orthopedic follow up. Standard AP and lateral images of the bone were examined for development of callus, formation of cortical bridges, presence of fracture line, and improvement of the fracture site. Progressive callus formation and bridging of cortices, with reduction of the fracture gap, were deemed to be adequate healing. Delayed fracture healing was diagnosed when radiographs failed to show acceptable radiographic healing within the expected time frame, plus the presence of persistent fracture lines, callus that was not adequate, or lack of cortical continuity on follow-up radiographs. A radiographic evaluation was conducted, with predetermined criteria, and recorded as normal/progressive healing or delayed healing. In addition, when applicable, the number of cortices with bridging was also noted to enhance the objectivity of the radiographic evaluation.

Data were entered and analyzed using IBM SPSS Statistics. Data from continuous variables (e.g. age, BMI, smoking duration, and smoking pack-years) were summarized as mean ± standard deviation or median with interquartile range (IQR) as appropriate, whereas data of categorical variables (e.g. smoking status) were summarized as frequencies and percentages. Chi-square analysis or Fisher's exact test was used to compare associations between categorical risk factors and delayed healing of fractures. Multivariate binary logistic regression was performed to assess independent predictors of delayed fracture healing, variables that were significantly associated with delayed fracture healing on bivariate analysis. Odds ratios with 95% confidence intervals were presented. A p-value <0.05 was considered statistically significant. The independent effects of smoking, poor nutritional status, low serum albumin, anemia, and low socioeconomic status on the risk for delayed radiographic fracture healing were emphasized.

RESULTS

Eighty-six patients with fractures were analyzed. The age of the subjects was 39.6 ± 13.7 years with the majority of patients aged between 31 and 45 years. The males made up 62.8% (n = 54) and females 37.2% (n = 32) of the study population. In all, 29 patients (33.7%) had radiographic features of delayed fracture healing at follow-up, while 57 patients (66.3%) had satisfactory radiographic evidence of progression toward fracture union.

Table 1. Demographic and socioeconomic characteristics of study participants (n = 86)

Variable	Frequency (n)	Percentage (%)
Age group (years)		
≤30	21	24.4
31–45	34	39.5
46–60	23	26.7
>60	8	9.3
Sex		
Male	54	62.8
Female	32	37.2
Residence		
Urban	47	54.7
Rural	39	45.3

Educational status		
No formal education	13	15.1
Primary	19	22.1
Secondary	32	37.2
Higher education	22	25.6
Employment status		
Employed	51	59.3
Unemployed	35	40.7
Socioeconomic status		
Low	31	36.0
Middle	38	44.2
High	17	19.8

Of the patients, the middle socioeconomic category represented the largest group (44.2%) followed by the low (36.0%) socioeconomic category. Almost 20% of the respondents had no jobs.

Table 2. Smoking and nutritional characteristics of participants

Variable	Frequency (n)	Percentage (%)
Smoking status		
Current smoker	35	40.7
Non-smoker	51	59.3
Smoking intensity among smokers (n = 35)		
Light (<10 cigarettes/day)	12	34.3
Moderate (10–20 cigarettes/day)	15	42.9
Heavy (>20 cigarettes/day)	8	22.9
BMI category		
Underweight	14	16.3
Normal weight	43	50.0
Overweight	20	23.3
Obese	9	10.5
Nutritional status		
Well nourished	55	64.0
At nutritional risk	20	23.3
Malnourished	11	12.8
Hemoglobin status		
Normal	58	67.4
Low	28	32.6
Serum albumin		
Normal (≥3.5 g/dL)	65	75.6
Low (<3.5 g/dL)	21	24.4

Current smoking was reported by 40.7% of patients. Moderate smoking was the most common smoking pattern among smokers. Around 36.1% of the participants were either malnourished or at risk of malnutrition. Low serum albumin was found in 24.4% and low hemoglobin in 32.6% of the patients.

Table 3. Clinical and fracture-related characteristics

Variable	Frequency (n)	Percentage (%)
Fracture site		
Tibia	29	33.7
Femur	23	26.7
Humerus	14	16.3
Radius/ulna	12	14.0
Other	8	9.3

Fracture type		
Closed	65	75.6
Open	21	24.4
Fracture pattern		
Simple	48	55.8
Comminuted	29	33.7
Segmental	9	10.5
Mechanism of injury		
Road traffic accident	49	57.0
Fall	27	31.4
Other	10	11.6
Post-treatment infection		
Present	13	15.1
Absent	73	84.9

The most common injury was tibial fractures, accounting for 33.7% of injuries. A total of 24.4% of the fractures were open while the remaining 75.6% were closed fractures. Over half of injuries were due to road traffic accidents.

Table 4. Radiographic characteristics of fracture healing

Radiographic finding	**Frequency (n)**	**Percentage (%)**
Adequate callus formation		
Yes	61	70.9
No/poor	25	29.1
Bridging of ≥3 cortices		
Present	59	68.6
Absent	27	31.4
Persistent fracture line		
Present	30	34.9
Absent	56	65.1
Overall radiographic healing		
Normal/progressive healing	57	66.3
Delayed healing	29	33.7

The radiographic evaluation showed that 70.9% of patients had adequate callus formation whereas 29.1% had inadequate or poor callus formation. Half of the patients (68.6%) had bridging of at least three cortices and one-third had a persistent fracture line. Using the pre-established radiographic parameters, the prevalence of delayed healing of fractures was 33.7%.

Table 5. Association of smoking, nutritional and socioeconomic factors with delayed fracture healing

Variable	**Delayed healing n/N (%)**	**Normal healing n/N (%)**	**p-value**
Smoking status			**0.004**
Smoker	18/35 (51.4)	17/35 (48.6)	
Non-smoker	11/51 (21.6)	40/51 (78.4)	
BMI category			**0.031**
Underweight	8/14 (57.1)	6/14 (42.9)	
Normal weight	11/43 (25.6)	32/43 (74.4)	
Overweight/obese	10/29 (34.5)	19/29 (65.5)	
Nutritional status			**0.006**
Well nourished	12/55 (21.8)	43/55 (78.2)	
At risk/malnourished	17/31 (54.8)	14/31 (45.2)	
Serum albumin			**0.003**
Low	13/21 (61.9)	8/21 (38.1)	
Normal	16/65 (24.6)	49/65 (75.4)	

Hemoglobin status			**0.041**
Low	14/28 (50.0)	14/28 (50.0)	
Normal	15/58 (25.9)	43/58 (74.1)	
Socioeconomic status			**0.018**
Low	16/31 (51.6)	15/31 (48.4)	
Middle	10/38 (26.3)	28/38 (73.7)	
High	3/17 (17.6)	14/17 (82.4)	
Education			0.072
None/Primary	15/32 (46.9)	17/32 (53.1)	
Secondary/Higher	14/54 (25.9)	40/54 (74.1)	
Employment status			0.084
Unemployed	16/35 (45.7)	19/35 (54.3)	
Employed	13/51 (25.5)	38/51 (74.5)	

Smokers were significantly more likely to have delayed fracture healing compared to non-smokers (51.4% smoked compared to 21.6%, p = 0.004). There was also significant association between the nutritional status and healing with delayed union seen in 54.8% of malnourished and/or nutritionally at risk participants, and in 21.8% of well-nourished participants (p = 0.006). A low level of serum albumin was found to be significantly related to delayed healing (61.9% vs. 24.6%, p = 0.003). Likewise, patients with low hemoglobin had a higher incidence of delayed healing. Socio-economic status was also statistically significant with delayed healing in 51.6% of patients in the low socioeconomic group versus only 17.6% in the high socioeconomic group (p = 0.018).

Table 6. Multivariable logistic regression for predictors of delayed fracture healing

Predictor	Adjusted OR	95% CI	p-value
Current smoking	3.21	1.22–8.43	**0.018**
At risk/malnourished nutritional status	2.84	1.07–7.56	**0.036**
Low serum albumin	3.47	1.18–10.20	**0.024**
Low socioeconomic status	2.73	1.01–7.39	**0.048**
Low hemoglobin	1.81	0.68–4.82	0.235
Open fracture	2.46	0.88–6.91	0.087

Even after adjusting for the relevant clinical and demographic factors, current smoking was an independent predictor of delayed fracture healing, with smokers having about three times the odds of delayed healing than non-smokers (AOR = 3.21, 95% CI: 1.22–8.43; p = 0.018). Malnutrition and nutrition risk also were associated with higher odds of delayed healing (AOR = 2.84, 95% CI: 1.07–7.56; p = 0.036). Another independent predictor was low serum albumin (AOR = 3.47, 95% CI: 1.18–10.20; p = 0.024) with patients having low serum albumin having about 3.5 times the probability of delayed radiographic healing. Delayed healing was independently associated with low socioeconomic status (AOR = 2.73, 95% CI: 1.01–7.39; p = 0.048). Open fractures and low hemoglobin were associated with higher odds of delayed healing, but this relationship was not statistically significant after adjustment. Overall, it was found that about one-third of the study population had delayed fracture healing on radiograph. The main factors associated with delayed fracture healing were smoking, low serum albumin, and socioeconomic disadvantage, particularly smoking and biochemical evidence of poor nutrition, which showed strong independent associations with delayed radiographic union.

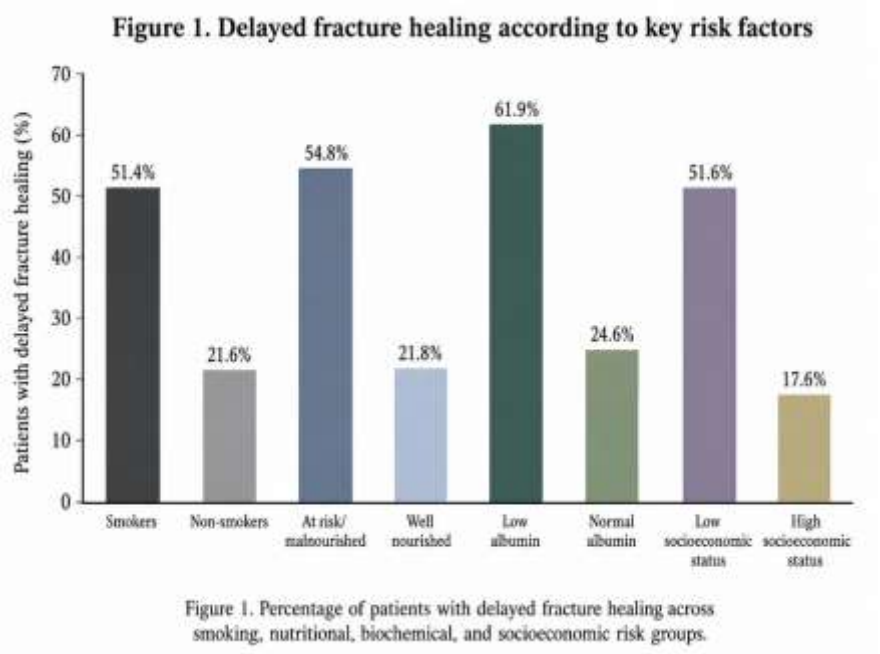

Figure 1. Percentage of patients with delayed fracture healing according to smoking status, nutritional status, serum albumin level, and socioeconomic status.

DISCUSSION

The present study demonstrated that delayed radiographic fracture healing was observed in approximately one-third of the participants, with 29 of 86 patients (33.7%) showing delayed progression toward union. Smoking, poor nutritional status, low serum albumin, and socioeconomic disadvantage showed significant relationships with delayed healing. Current smokers had a considerably higher proportion of delayed healing than non-smokers (51.4% vs. 21.6%), and smoking remained an independent predictor after multivariable adjustment. This observation is consistent with previous evidence showing that cigarette smoking adversely affects bone regeneration and increases the probability of delayed union and nonunion. Studies reported, tibial shaft fractures reported that smoking was associated with increased rates of delayed union, nonunion, and prolonged time to fracture union. Review involving more than 400,000 patients found that smokers had significantly greater odds of nonunion following treatment of non-pathological fractures, with a pooled odds ratio of approximately 2.5 compared with non-smokers. These findings support the biological explanation that smoking may impair fracture repair through reduced tissue oxygenation, altered vascularization, and disruption of osteoblast-mediated bone formation (10, 11).

Nutritional status was another important determinant of fracture healing in this study. Of those who were malnourished or nutritionally at risk, 54.8% experienced delayed healing, whereas 21.8% of those well-nourished experienced delayed healing. In addition, delayed healing was especially strongly associated with low serum albumin, as the healing time was delayed in 61.9% of the patients with hypoalbuminemia and 24.6% of those with normal serum albumin. Poor nutritional status and low serum albumin were independent risk factors for delayed healing after controlling for other factors. These results are clinically relevant as there is a need for sufficient protein, energy, mineral and micronutrient supply for inflammatory signaling, collagen production, callus formation, angiogenesis and bone remodeling during fracture repair. Malnutrition has also been shown in modern studies to be linked with the risk of nonunion and poor outcomes after fracture treatment. Recent evidence mapping studies have reported a significant association between malnutrition and nonunion and postoperative complications. Thus, nutritional screening at the time of fracture presentation may offer a window of opportunity to identify modifiable risk factors that can negatively impact the fracture healing process (12-15).

On bivariate analysis, delayed union was also associated with low hemoglobin, with 50.0% of the patients with low hemoglobin having delayed union as opposed to 25.9% of the patients with normal hemoglobin levels. This relationship, however, was not significant

following adjustment for other predictors. This indicates that anemia may play a role in the impaired fracture healing but it may be a part of a greater nutritional and clinical deficiency. The supply of adequate oxygen is necessary for the angiogenesis, cellular metabolism and mineralization during bone regeneration. Likewise, in the current study, patients with underweight were observed to have a greater prevalence of delayed healing than normal BMI. These results highlight the importance of using BMI as just one predictor of nutritional status as patients may still have clinical protein and/or micronutrient deficiencies despite a normal or high BMI. The estimation of serum albumin, hemoglobin, dietary intake, and other nutritional parameters may, therefore, give a more holistic picture of the patient's physiological ability to repair his/her bones (16, 17).

Fracture healing was also found to be significantly related to socioeconomic status. A higher proportion of patients in the low SES group had delayed healing (51.6%) than patients in the high SES group (17.6%). Multivariable adjustment failed to change the association of low socioeconomic status with delayed radiographic healing. The same finding has been noted in orthopedic trauma patients. A study of social deprivation following tibial shaft fracture showed that patients from the most deprived areas had about a 31% increase in the time to radiographic union versus those from the least deprived areas. More recent studies have also shown higher complication rates and poorer outcomes in the patients with more severe socioeconomic deprivation following fixation of humeral shaft fractures. Socioeconomic disadvantage can be associated with poor healing outcomes indirectly, because of poor nutrition, less access to rehabilitation, transportation issues, not following-up regularly, work requirements, cost of treatment, and smoking or other unhealthy lifestyle habits. Thus, socioeconomic factors should be taken into account along with biological and fracture-related factors in determining who is susceptible to delayed union (18-20).

The findings of the present study have important clinical implications because several identified determinants of delayed healing are potentially modifiable. Optimization of the biological and behavioral environment needed for fracture repair may be achieved with smoking cessation counseling, early nutritional screening, correcting protein deficiency and anemia, and providing other support to patients who are at risk for socioeconomic barriers to quitting smoking. Further evidence exists that smoking cessation can help lower postoperative complications, reinforcing the merit of its integration into orthopedic care plans. However, some restrictions need to be noted. The study was performed in one institution and included a relatively small number of patients (86) and might not be generalizable. Association is determined by the observational design and causality cannot be inferred, and self-reported smoking and socioeconomic data may be subject to reporting bias. Furthermore, fracture healing was also affected by various other factors which might not have been fully controlled, such as fracture severity, fixation stability, infection, diabetes, medication, and vitamin D status as well as compliance with weight bearing recommendations. Further multicenter prospective studies with larger patient numbers, universally accepted radiographic scoring, serial biochemical assessments and quantification of smoking exposure and nutritional deficiencies are suggested to confirm the findings and to evaluate the effects of targeted interventions on fracture union time.

CONCLUSION

Delayed radiographic fracture healing was relatively common in the studied population and was significantly associated with smoking, poor nutritional status, low serum albumin, and socioeconomic disadvantage. Current smokers and patients with biochemical or clinical evidence of inadequate nutrition had substantially greater odds of delayed healing, while low socioeconomic status remained an important independent predictor after adjustment for other factors. These findings indicate that fracture healing is influenced not only by the characteristics of the injury but also by modifiable behavioral, nutritional, and social determinants. Incorporating smoking cessation, nutritional assessment and optimization, and appropriate socioeconomic support into routine fracture management may help identify high-risk patients early and potentially improve fracture-healing outcomes.

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