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Smoking Increases Risk of Symptomatic Nonunion after Four-Corner Arthrodesis

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Abstract

Background: Nonunion remains prevalent among patients undergoing scaphoidectomy and Four-Corner Arthrodesis (FCA) despite advances in patient selection and surgical technique. This study examined smoking along with other patient and surgical factors to determine their effect on union in patients undergoing FCA.

Methods: A retrospective review was conducted of consecutive cases of FCA completed at our tertiary referral institution between 2001 and 2016. Two-hundred twelve cases were identified. After exclusion criteria applied, 148 procedures performed in 146 patients (111 men, 35 women; mean age 50.8 years) with an average follow-up of 26.2 months (4 to 154 months) were included for analysis. Charts were reviewed for smoking status and other patient and surgical characteristics. The primary outcome measure was symptomatic nonunion. Subjects were separated by outcome, group 1 (union) and group 2 (symptomatic nonunion) and analyzed.

Results: Thirty-seven of the 148 wrists (25.0%) developed symptomatic nonunion. Group 1 (union) and group 2 (nonunion) subjects consisted of 111 and 37 wrists, respectively. Smoking status differed significantly between the two groups (24.3% and 43.2%, respectively). Sixteen of 43 (37.2%) smokers developed symptomatic nonunion compared to 21 of 105 (20%) nonsmokers. Union did not differ significantly with respect to age, gender, diabetes mellitus, indication, fixation construct, or source of bone graft.

Conclusion: Perioperative smoking is a significant risk factor for development of symptomatic nonunion following FCA. We recommend all patients considering four-corner arthrodesis be counseled regarding the high risk of nonunion in smokers.

Keywords: Arthrodesis; Four-corner fusion; Nonunion; Tobacco; Wrist

Introduction

Scaphoidectomy with Four-Corner Arthrodesis (FCA) is a well-established surgical treatment for certain patterns of wrist arthritis which allows the preservation of functional motion while stabilizing the carpus. The rate of nonunion after this procedure has been reported to range 0% to 31% in multiple clinical studies [1-3]. While smoking is a known risk factor, nonunion after arthrodesis has been attributed to multiple factors, including host factors, such as patient health and age, as well as technical elements, such as strength of fixation constructs the use of bone graft and adequacy of bony preparation. Within the recent literature, choice of hardware and fixation techniques for FCA has received attention as possible modifiable risk factors for nonunion. Even with advances in implant techniques, including the development of circular plate fixation techniques, nonunion is not infrequent [4,5].

Substantial literature exists documenting the deleterious effects of tobacco smoking on bone healing and health. Studies examining the effects of nicotine and tobacco use on fusion rates after spinal surgery, ankle arthrodesis or fracture have demonstrated an increase of nonunion in smokers [6-9]. While risks of tobacco use concurrent to bony arthrodesis procedures is well known, few studies have investigated the specific effects of smoking on FCA.

In the author's clinical practice, there is a large smoking population and nonunion remains prevalent in FCA. It was hypothesized that the patient smoking rate would be significantly higher in those that went on to nonunion compared to those with united fusions. The purpose of this

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study was to examine if there is an association between smoking and nonunion in FCA. The secondary goal of this study was to analyze other demographic and operative conditions and a potential association with nonunion.

Materials and Methods

This study was approved by the Institutional Review Board. A retrospective review of consecutive cases of FCA completed at our tertiary referral institution from January, 2001 to December, 2016 was conducted.

Subjects

Inclusion criteria included patients age of 18 or older, minimum follow-up at least four months, and documented smoking status. Patients were identified by a focused query of our medical records using the procedure codes 25820 and 25825. Once identified, medical records were systematically reviewed to confirm eligibility. Patient demographic data was recorded including age at the time of surgery, sex, laterality, smoking status, diabetes mellitus, surgical indication, type of fixation used, source of bone graft used, and follow-up duration. Smoking pack-years were not recorded or calculated as documentation was incomplete to consistently use this data point. The primary endpoint for this study was symptomatic nonunion. All patients who required revision surgery were noted, and the details of that revision surgery recorded. Attention was paid to the indication for revision surgery along with time interval between index and revision surgery. The radiographs of all symptomatic patients were reviewed by two independent reviewers to verify the presence of union or nonunion. Successful radiographic fusion was determined by observation of solid trabeculation across the intercarpal articulations without persistent joint lines on serial radiographs. Symptomatic nonunion was defined as clinically persistent wrist pain and dysfunction in combination with radiographic failure of solid bone fusion six months after the index procedure, or at time of revision surgery. Computed tomography scans were rarely obtained and therefore not reviewed. Patients were divided into two groups according to whether they had union (group 1) or symptomatic nonunion (group 2) as seen in Figure 1. Patients that were diagnosed with clinically asymptomatic nonunion were included in group 1. Those that were diagnosed with symptomatic nonunion but lost to follow-up before revision surgery were included in group 2.

Statistical analysis

Priori power analysis was first conducted for sample size estimation. Given an effect size of 0.20 with an enrollment ratio of 2.5, alpha =0.05, and power =0.80, the determined sample size needed to adequately power the study was n=95 with at least 68 subjects in Group 1 and 27 in Group 2. Univariate analysis was performed with student t-test used for comparison of continuous variables and the Fisher's exact test was used for comparison of categorical variables. Odds Ratios (OR) with the corresponding 95% Confidence Interval (CI) was calculated for all independent variables. In all analyses, $p<0.05$ was considered to indicate significance.

Study demographics

Two-hundred and twelve consecutive cases of scaphoidectomy and FCA were identified in 210 patients. Once inclusion and exclusion criteria were applied, 148 procedures in 146 patients qualified for this study. Sixty-four patients were excluded for failing to meet follow-up requirements. Twenty-one patients were healed or healing at last follow-up and allowed to return as needed to clinic. The

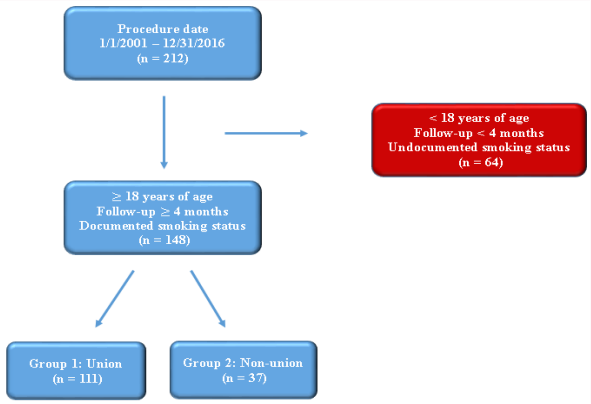

Figure 1: Study profile; n: number of wrists.

remaining 43 patients excluded were either lost to follow-up or had incomplete documentation as to the reason of termination of follow-up. Mean clinical follow-up was 26.2 months (range 4-154 months). One-hundred thirteen wrists were male (76.4%). Mean age at the time of surgery was 50.8 years (range 22 to 81). Diagnoses were Scapho-Lunate Advanced Collapse (SLAC, n=81, 54.7%), Scaphoid Nonunion Advanced Collapse (SNAC, n=43, 29.1%), and arthritis not otherwise specified (n=24, 16.2%). Forty-three patients (29.1%) were identified as smokers. Eighteen patients (12.2%) had a past medical history of diabetes mellitus. Implants utilized for fusion included dorsal "spider" -type plates (n=128, 86.5%), staples (n=15, 10.1%), cannulated screws (n=4, 2.7%), and K-wires (n=1, 0.7%). Bone graft types utilized were scaphoid autograft (n=68, 45.9%) compared to distal radius autograft (n=76, 51.4%). One case with iliac crest bone and Bone Morphogenic Protein (BMP) (n=1, 0.7%), and five cases which had undocumented bone graft type (n=5, 3.4%) were not included in statistical analysis of bone graft variables.

Surgical technique

Procedures were performed by one of three hand-fellowship trained surgeons at a single tertiary institution. In all cases, the carpus was approached dorsally through a longitudinal incision. The scaphoid was identified and excised, and the capitate, lunate, triquetrum and hamate were then denuded of any remaining articular cartilage. Kirschner wires were used to provisionally reduce and hold the carpus. A final fixation construct was then applied and autologous bone graft was placed to increase fusion rates. All patients were placed in a plaster wrist-splint for typically 10-14 days. Patients were generally followed up with at two weeks, six weeks, and three months. Most also followed up at six months and one year post-operatively.

Results

Thirty-nine of 148 wrists (26.4%) developed nonunion with 37 (25.0%) of these that became symptomatic. Thirty-five of the 148 wrists (23.6%) underwent revision surgery for nonunion, at a mean interval of 15.5 months (range 2-90). Two patients with symptomatic nonunion were lost to follow-up before planned revision was undertaken. Group 1 (union and asymptomatic nonunion) and group 2 (symptomatic nonunion) subjects consisted of 111 and 37 wrists, respectively. A univariate analysis of demographic and surgical characteristics is shown in Table 1. Twenty-seven of 111 patients (24.3%) in group 1 were identified as smokers, compared to 16 of 37 patients in group 2 (43.2%). Smoking status differed significantly between the two groups with the symptomatic nonunion

Table 1: Comparison of groups, n: number of wrists; SD: Standard Deviation; DR: Distal Radius; S: Scaphoid.

Variable	Group 1 (Union, n = 111)	Group 2 (Sx nonunion, n=37)	P Value
Age, y, mean (SD)	51.7 (13.0)	48.2 (10.7)	0.1333
Male sex, n (%)	86 (77.5)	27 (73.0)	0.5771
Smokers (%)	27 (24.3)	16 (43.2)	0.0282*
Diabetes mellitus (%)	15 (13.5)	3 (8.1)	0.3837
Indication (SLAC:SNAC: Other)	63:32:16	18:11:8	0.5406
Fixation (Dorsal plate: Other)	98:13	30:7	0.2668
Bone Graft Used (DR:S)	57:50	17:18	0.629

Table 2: Association with nonunion amongst independent variables. OR: Odds Ratio; CI: Confidence Interval.

Variable	OR	95% CI	P Value
Age<50	1.661	0.784-3.518	0.1853
Male	0.785	0.335-1.839	0.5771
Smoking	2.370	1.085-5.180	0.0305*
Diabetes mellitus	0.565	0.154-2.072	0.3889
Indication (SLAC)	0.722	0.342-1.522	0.3918
Use of Dorsal Plate	0.569	0.208-1.554	0.2711
Use of Distal Radius Bone Graft	0.829	0.386-1.779	0.6292

group having an association with smoking (p=0.028). Subjects were also sub-grouped based on smoking status. Sixteen of the 43 (37.2%) smokers went on to symptomatic nonunion compared to 21 of 105 (20.0%) nonsmokers (p=0.028) with a relative risk of 1.86 [95% CI (1.079-3.209); p=0.026]. The odds ratio of symptomatic nonunion in smokers was 2.370 [95% CI (1.085-5.180); p=0.031] as seen in Table 2. Groups 1 and 2 did not differ significantly with respect to age (51.7 and 48.2 years, p=0.133), gender (77.5% and 73.0% male, p=0.577), diabetes mellitus (13.5% and 8.1%, p=0.384), indication (SLAC, SNAC, or other; p=0.541), fixation construct (dorsal plating *vs.* traditional, p=0.267), or source of bone graft (distal radius *vs.* scaphoid, p=0.629). Twelve of the united patients (8.1%) ultimately underwent further procedures for indications other than nonunion including symptomatic hardware (n=5), progression of arthritis, (n=2), infection (n=2), arthrofibrosis (n=2), and radiocarpal subluxation (n=1). Four other patients were diagnosed with nonunion but not revised at our institution. Two were nonsmokers and both had asymptomatic nonunions radiographically that did not require revision surgery. The other two (one smoker, one nonsmoker) were diagnosed with nonunion and scheduled for revision but ultimately lost to follow-up.

Discussion

The risk of nonunion requiring revision surgery after scaphoidectomy and four-corner arthrodesis represents a challenge to the hand surgeon. Nonunion lengthens patient recovery times, frequently keeps patients from returning to premorbid recreational and occupational activities, and often requires revision surgery. While the link between smoking and impaired bone healing is well established, the specific rates of nonunion after FCA vary widely in reported literature. For this reason, this study examined the association between smoking and nonunion after FCA.

The risks of nonunion among active smokers has been well documented in the orthopedic literature, with multiple studies demonstrating increased relative risks of nonunion for smokers [10,11-30]. Within the upper extremity literature, a higher delayed union and nonunion rate has been demonstrated following ulnar shortening osteotomy (67.7% *vs.* 33.6%; p<0.001) [10]. This study echoes the findings of previous studies and demonstrates a significantly increased risk of symptomatic nonunion associated with smoking. Our symptomatic nonunion rate of 25.0% is similar to previously quoted studies, which range from <5% to as higher rates up to 31% [1,2,5,14,20,21]. While our study demonstrates results at the upper end of this range, we propose that this may be due to the relatively high proportion of smokers in our state of Ohio. While the overall prevalence of smoking in the United States is reported at 15.1% [11], the reported prevalence of smokers in Ohio is 23.4%, which is closer to our observed smoking rate of 29.1% [11].

Recent literature on outcomes of four-corner arthrodesis has focused on the use of specific fixation techniques as possible risk factors for delayed union or nonunion following FCA. Vance et al. [7] demonstrated a 26% nonunion rate associated with dorsal plate fixation compared to 3% rate in cases utilizing either K-wires or Herbert screws. A similar study at our institution [12] reported a 22% nonunion rate with dorsal circular plates, while several other studies have demonstrated a higher nonunion rate in FCA procedures utilizing dorsal plates as compared with traditional K-wire fixation [13-15]. While the present study is not appropriately powered to detect differences in union rates related to implant type, out data suggests that fixation type may be less significant than smoking status. Diabetes has been investigated in multiple studies related to bone healing, and been shown to play a key role in the development of nonunion. With respect to union rates following FCA, the present study demonstrated no association between diabetes and symptomatic nonunion.

Several specific limitations of our study merit mention. The retrospective nature of the study imparts inherent limitations including lack of randomization and potential for selection bias. Our study design did not specifically control for variations in surgical technique and post-operative protocol, which have been hypothesized to influence nonunion rates. While we did routinely utilize bone graft, variable graft types were utilized. We implemented

the routine use of distal radius autograft during FCA starting around 2008 around the time published literature suggested its superiority to scaphoid autograft in cases of FCA [16]. We also had some difficulty extracting data retrospectively, particularly early in the study period before electronic medical records were implemented. Searching for social history, past medical history, and bone graft material was often difficult and occasionally inconclusive. We elected to designate patients as smokers only if smoking status was documented. Former smokers were considered nonsmokers for this study. However, it stands to reason that some documentation may have been lacking, or that patients might be less-than truthful regarding smoking status, and that some smokers might be misidentified. Our simple designation of "smoker" or "nonsmoker" is also problematic, and does not consider the possibility that tobacco has a graded effect. Quantification of smoking pack-years was not calculated due to substantial variations in documentation and inability to reliably obtain that data point. Nor did we include patients who used smokeless tobacco as smokers.

Additionally, some patients excluded from this study were patients doing well around the three-month post-operative visit that were discharged or lost to follow-up. In total, 64 patients were excluded because they failed to have documented follow-up for four months post-operatively. This happens frequently in our practice, as we find that many patients who are doing well are unenthusiastic regarding perceived "unnecessary" follow-up. Repeating the study with a larger sample size and improved structure of follow-up standards regardless of healing status would be beneficial going forward to improve validity. Lastly, all parameters of interest were analyzed in a univariate fashion with no multivariate analysis performed.

Nonunion remains a concern for the hand surgeon. This study demonstrates a significant association between smoking and development of symptomatic nonunion following four-corner arthrodesis. We suggest the continued emphasis of smoking cessation to improve surgical outcomes following four-corner arthrodesis.

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