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ORIGINAL ARTICLE

Enhanced scaphoid fixation with Kirschner wire: A clinical and finite element study

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ABSTRACT

Objectives: This study aims to assess the effect of addition of a Kirschner wire (K-wire) to a headless compression screw on biomechanical and clinical outcomes in the treatment of scaphoid fractures and nonunions.

Patients and methods: Between January 2020 and November 2023, a total of 23 patients (20 males, 3 females; mean age: 29.7±7.2 years; range, 18 to 43 years) who underwent surgical treatment for scaphoid fractures and nonunion were retrospectively analyzed. The patients were divided into two groups: those who received only a headless compression screw (Group 1), and those who received both a screw and a supplementary K-wire, which was removed after three months (Group 2). In cases of nonunion, autografting was also performed. Postoperative clinical outcomes were evaluated using Visual Analog Scale (VAS), Mayo Wrist Score, and Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH). Finite element analysis was conducted to assess the biomechanical performance of both fixation methods.

Results: Patients treated with screw combined with the K-wire demonstrated significantly improved postoperative functional scores and lower pain levels compared to those treated with screw alone (p=0.011 for VAS, p=0.027 for Mayo Wrist Score and p=0.009 for QuickDASH). Finite element analysis revealed a reduction in stress concentration at the fracture site in the screw + K-wire group.

Conclusion: The addition of a K-wire to screw fixation seems to enhance biomechanical stability and clinical outcomes in scaphoid fractures. These findings suggest that K-wire augmentation may be a beneficial strategy for improving healing and reducing postoperative discomfort.

Keywords: Acutrak™ screw, finite element analysis, Kirschner wire, nonunion, scaphoid fracture.

The scaphoid is the most commonly fractured carpal bone, accounting for approximately 60% of all carpal fractures.[1] Scaphoid fractures occur predominantly in young, active males, a patient population with high functional demands and expectations for daily living activities.[2] Early diagnosis and prompt treatment are crucial to prevent complications.[3] The primary mechanism of injury involves a fall onto an outstretched hand with wrist hyperextension exceeding 95º, often accompanied by slight radial deviation.[4]

The unique vascular supply of the scaphoid bone makes it particularly susceptible to nonunion, when diagnosis and treatment are delayed.[5] Its blood supply is derived from the dorsal and palmar superficial branches of the radial artery. This

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vascular pattern creates a retrograde blood flow from distal to proximal. Consequently, the proximal segment of the scaphoid has a weaker blood supply, making it more prone to avascular necrosis and nonunion.[6]

Currently, fixation using headless compression screws is the current gold standard for surgical management.[7] In cases of nonunion, autografts from the distal radius or iliac crest can be utilized in conjunction with surgical fixation to enhance healing. Considering the higher morbidity associated with the iliac crest donor site, several studies support the preferential use of distal radius autografts.[8] Depending on patient characteristics and fracture type, surgical approaches can be open or percutaneous, utilizing either a dorsal or volar approach.[9]

In the present study, we aimed to evaluate the effectiveness of using Kirschner wires (K-wires) combined with screws for the surgical treatment of scaphoid fractures using clinical scoring and finite element analysis (FEA) and to determine its effect on fracture stability and patient outcomes.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Ankara Bilkent City Hospital, Department of Orthopedics and Traumatology between January 2020 and November 2023. A total of 23 patients (20 males, 3 females; mean age: 29.7±7.2 years; range, 18 to 43 years) who underwent surgical treatment for scaphoid fractures and nonunion were included. Only patients who were diagnosed with acute scaphoid fractures and opted for surgical treatment and aged >18 years with prior scaphoid fractures who developed nonunion following conservative management were considered eligible. Pediatric patients, individuals requiring revision surgery, and patients who underwent surgery at an external center with signs of infection were excluded. Written informed consent was obtained from each patient. The study protocol was approved by the Ankara Bilkent City Hospital Ethics Committee (Date: 13.12.2023, No: 4398). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Surgical procedure

Surgical treatment was indicated for patients aged over 18 years with scaphoid fractures who had no prior surgical intervention, exhibited radiographic evidence of humpback deformity, and demonstrated failure of fracture union following an adequate course of conservative management. All patients were evaluated, surgically indicated, and followed postoperatively by a single hand surgeon. Nonunion was defined as the absence of fracture healing at the end of a six-month follow-up period following conservative treatment. Open reduction was performed in all patients. A dorsal surgical approach was favored in the management of proximal pole fractures and their nonunions, whereas a volar approach was predominantly utilized for fractures and nonunions located at the scaphoid waist. Of a total of 23 patients included in the study, a K-wire was positioned in parallel alignment with the Acutrak™ (Acumed, OR, USA) screw in 12 cases.

As part of the treatment process, patients were assigned in a random manner to one of two treatment groups: either screw-only fixation (Group 1) or screw combined with a K-wire during routine clinical practice (Group 2). This allocation was carried out without reliance on any predefined algorithm or selection criteria based on patient characteristics. The group assignment was independent of fracture type, complexity, or surgeon preference. Therefore, no systematic allocation bias was present in the formation of treatment groups.

Following fracture reduction under fluoroscopic guidance, two parallel 1.2-mm Acutrak™ K-wires were inserted perpendicular to the fracture line. A 2.4 mm Acutrak™ screw was, then, placed over one of the K-wires, while the other wire was cut and retained subcutaneously (Figure 1). In cases of nonunion, autograft harvested from the distal radius or the iliac crest was utilized.

Postoperatively, patients were initially immobilized with a splint for a period of two weeks. Subsequently, sutures were removed, and a scaphoid cast, supported by the thumb, was applied for an additional four weeks. At the six-week timepoint, the scaphoid cast was removed, and patients were transitioned to a splint. Mobilization exercises were commenced while using the splint, and the splint was fully removed by Week 8.

Fracture healing was assessed through computed tomography (CT) imaging at an average of three months postoperatively. In cases where healing was confirmed on the CT scan, the K-wire was subsequently removed.

Clinical follow-up and assessment

Patients who underwent surgical treatment were followed during outpatient clinic visits on

FIGURE 1. Anteroposterior radiograph of a 30-year-old male on the first postoperative month after fixation with one screw and a Kirschner wire (K-wire).

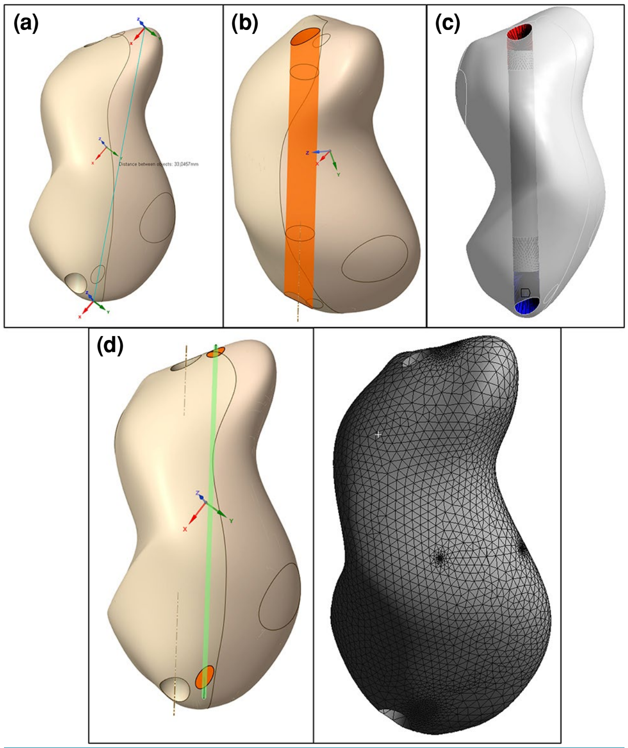

FIGURE 2. Three-dimensional (3D) modeling of the scaphoid using SIEMENS NX: **(a)** general model, **(b, c)** entry and exit points, **(d)** Acutrak™ screw travel distance.

postoperative Day 15 and at one, three, six, and 12 months. Fracture healing was monitored through serial radiographs throughout the follow-up period, and a detailed assessment was performed using CT at the third postoperative month. In the group treated with K-wires, the wires were removed, if union was confirmed on CT. Functional outcomes were evaluated between 10 and 14 months postoperatively (average: 12 months) using the Visual Analog Scale (VAS) for pain assessment, the Mayo Wrist Score for wrist function, and the Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) questionnaire for patient-reported disability.

Finite element analysis modeling

Three-dimensional digital modeling of the scaphoid bone was performed using Siemens NX software (Siemens AG., München, Germany) prior to the analysis. Finite element analysis was subsequently conducted using ANSYS 2023R2 (ANSYS Inc., Pennsylvania, USA) with a static analysis approach. The scaphoid bone and implant components were modeled using SOLID187 elements, which are 10-node, second-order tetrahedral elements with quadratic displacement functions. These elements provide high-resolution modeling capability, thereby enhancing numerical accuracy in anatomically complex regions. Drill holes suitable for the insertion of an Acutrak™ screw and a K-wire were defined on the model (Figure 2).

In the geometric model, the fracture line was defined as a circular surface with a diameter of 8 mm (Figure 3). This crack surface was positioned to accommodate the bidirectional loading and was integrated into the model to evaluate the local stress distribution during load transfer. The FEA was performed under two separate scenarios. In the first model, the K-wire was included alongside the screw, while in the second model, the wire body was suppressed and only the screw was analyzed. This allowed for a comparative evaluation of the wire's contribution to mechanical stability.

The wire was modeled with bonded contact at the bone-implant interface. In contrast, the screw was incorporated using a remote point connection, allowing load transmission without direct physical

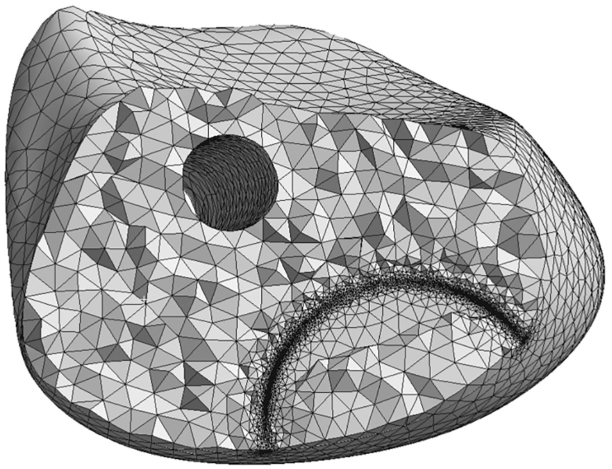

FIGURE 3. Fracture line simulation on the scaphoid model for finite element analysis.

contact with the geometry. This method enables interaction through a defined virtual coupling surface. All analyses were performed under the small deformation assumption using linear elastic material properties and a linear static solution approach. Time-dependent dynamic effects were not considered in this study.

A uniform mesh structure was generated using elements of equal size throughout the model. To improve solution accuracy in critical regions, the mesh density was increased around the fracture site by reducing the local element size to approximately 1/200 of the crack length. Although a global convergence study was not performed, a local convergence assessment based on the stress intensity factor (SIF) values at the crack tip was conducted. The absence of significant variation in SIF values with increasing mesh density confirmed that the numerical solution was mesh-independent.

A static axial load was applied longitudinally along the scaphoid. The proximal pole of the scaphoid was fixed to define the boundary conditions. A pretension force of 300 N was applied to the screw, and additional forces of 200 N were assigned independently along the X and Z axes of the scaphoid (Figure 4).

Fracture mechanics and stress intensity factor calculation

In fracture mechanics:

K1 represents the opening mode.

K2 represents the sliding mode.

K3 represents the tearing mode.

All three fracture types were simulated using computer modeling. For each fracture type, two models were created: 1) Fixation with one screw only and 2) Fixation with one screw + one K-wire.

The SIF was measured at the fracture line under applied forces along the X and Z axes to compare stress-strain intensities in both fixation models.

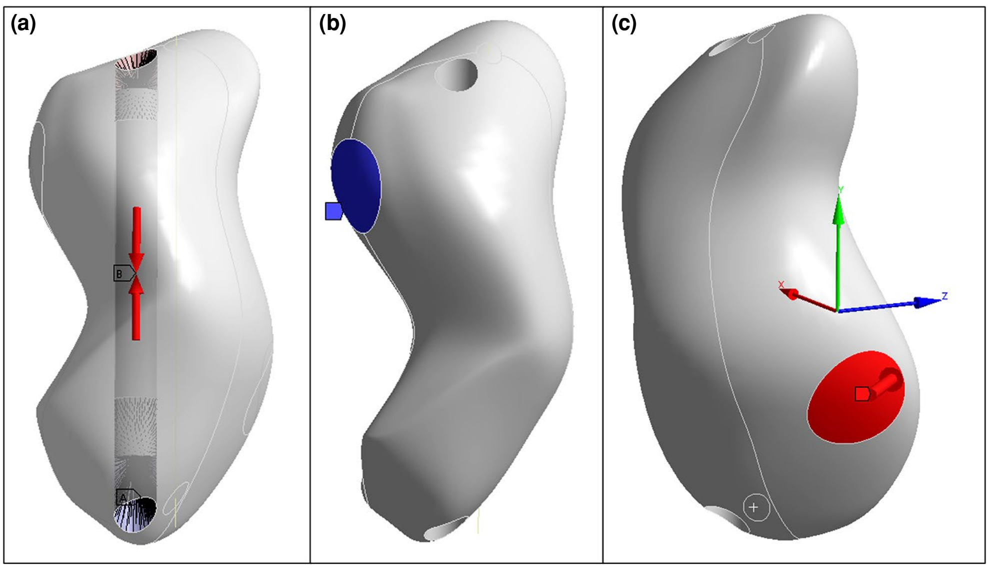

FIGURE 4. Graphical representation of the boundary conditions applied to the scaphoid model. **(a)** A pretension force of 300 N was applied to the screw. **(b)** The proximal pole of the scaphoid was fixed. **(c)** An external load of 200 N was applied to the scaphoid along the X and Z axes.

Definition and importance of stress intensity factor

The SIF is a key parameter in fracture mechanics that quantifies the stress intensity around a crack or fracture site, and is expressed in units of MPa√m. This factor, denoted by the letter K, quantitatively represents the stress intensity around the crack tip. In engineering, the SIF serves as a criterion for crack growth prediction, and when the SIF exceeds the material's fracture toughness, it leads to rapid and unstable fracture propagation. A lower SIF value indicates greater stability.[10] This study utilized SIF to assess the relative stability of different fixation methods.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency. Categorical variables were analyzed using exact methods where appropriate, including the Fisher exact test, continuity correction chi-square test, and Pearson chi-square test for between-group comparisons. For continuous variables, the independent samples t-test was used for normally distributed data, while the Mann-Whitney U test was applied for non-normally distributed data. Non-parametric tests were selected based on distributional characteristics where applicable. All results were reported with appropriate levels of precision in accordance with the statistical reporting guidelines recommended by Bailar and Mosteller. A *p* value of <0.05 was considered statistically significant with 95% confidence interval (CI).

RESULTS

Of a total of 23 patients, waist fractures were observed in 15 (65.2%), proximal pole fractures in seven (30.4%), and distal pole fractures in one (4.3%). In terms of fixation methods, 11 (47.8%) patients were treated with a single screw, while 12 (52.2%) patients received one screw and one K-wire. In the surgical treatment, the volar approach was preferred in 14 (60.9%) patients, while the dorsal approach was used in nine (39.1%) patients (Table I).

The distribution of surgical approaches was not balanced between the treatment groups and showed a statistically significant difference (volar: 36.4% in Group 1 *vs.* 83.3% in Group 2; p=0.021). However, this difference was attributable to the anatomical location of the fractures rather

TABLE I
Demographic characteristics of the study cohort

	n	%	Mean±SD	Median	Min-Max
Age (year)			29.7±7.2	29.0	18-43
Sex					
Male	20	87.0			
Female	3	13.0			
Side					
Right	9	39.1			
Left	14	60.9			
Fracture type					
Waist	15	65.2			
Proximal pole	7	30.4			
Distal pole	1	4.3			
Approach					
Volar	14	60.9			
Dorsal	9	39.1			
Treatment					
1 Screw	11	47.8			
1 Screw+1 K-wire	12	52.2			
Time until surgery (month)			5.3±8.5	2.0	0.2-36.0

SD: Standard deviation.

than the fixation method. The volar approach was predominantly utilized for waist fractures, whereas the dorsal approach was preferred in cases involving the proximal pole.

Except for the chosen surgical approach, no statistically significant differences were observed between the groups in terms of demographic characteristics and fracture patterns (Table II).

There was a difference in the mean duration from injury to surgery between the two groups, possibly stemming from the time interval between the injury and the surgical intervention; however, it was not statistically significant and did not affect the outcomes of the study (p=0.901).

The functional outcomes of both groups were assessed at an average follow-up period of 12 months. Patients in Group 2 demonstrated significantly improved clinical outcomes compared to those in Group 1. The mean VAS score was 2.0±2.3 in Group 1 and 0.1±0.3 in Group 2 (p= 0.011). The mean Mayo Wrist score was 84.6±16.3 in Group 1 and 96.3±3.1 in Group 2 (p=0.027), while the QuickDASH score was 7.2±7.2 in Group 1 and 1.7±2.1 in Group 2 (p=0.009) (Table III).

Based on the categorical classification of the Mayo Wrist score, Group 1 included 6 patients rated as excellent, three as good, and two as fair, whereas Group 2 included 10 patients rated as excellent and two as good.

In addition to statistical significance, 95% CIs were calculated to assess the precision of the clinical scores.

The FEA was conducted to evaluate fracture stability and stress intensity at the fracture line.

TABLE II
Comparative demographic data by treatment group

	Group 1 (n=11) (1 Screw)					Group 2 (n=12) (1 Screw + 1 K-wire)					
	n	%	Mean±SD	Median	Min-Max	n	%	Mean±SD	Median	Min-Max	*p*
Age (year)			30.7±7.6	30	18-43			28.6±7.1	27	22--41	0.413*
Sex											0.484+
Male	9	81.8				11	91.7				
Female	2	18.2				1	8.3				
Side											0.147+
Right	6	54.5				3	25.0				
Left	5	45.5				9	75.0				
Fracture type											0.141+
Waist	5	45.5				10	83.3				
Proximal pole	5	45.5				2	16.7				
Distal pole	1	9.1				0	0.0				
Approach											0.021+
Volar	4	36.4				10	83.3				
Dorsal	7	63.6				2	16.7				
Associated injury											0.949+
No	10	90.9				11	91.7				
Distal radius fracture	1	9.1				1	8.3				
Graft											0.125+
No	4	36.4				6	50.0				
Iliac crest	1	9.1				4	33.3				
Distal radius	6	54.5				2	16.7				
Nonunion											0.795+
Yes	7	63.6				7	58.3				
No	4	36.4				5	41.7				
Time until surgery (month)			3.5±3.4	2.0	0.5-12.0			7.0±11.3	2.0	0.2-36.0	0.901*

SD: Standard deviation; + Pearson Chi-Square; * Mann-Whitney U-test.

TABLE III
Comparative clinical score data by treatment group

	Group 1 (n=11) (1 Screw)			Group 2 (n=12) (1 Screw + 1 K-wire)			
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*
VAS score	2.0±2.3	2.0	0.0-7.0	0.1±0.3	0.0	0.0-1.0	0.011
Mayo Wrist score	84.6±16.3	95.0	55.0-100.0	96.3±3.1	95.0	90.0-100.0	0.027
QuickDASH score	7.2±7.2	4.5	0.0-25.0	1.7±2.1	0.0	0.0-4.5	0.009

SD: Standard deviation; VAS: Visual Analog Scale; QuickDASH: Quick Disabilities of the Arm, Shoulder and Hand Questionnaire; * Mann-Whitney U-test.

The results correlated with clinical scoring, confirming that patients treated with one screw + one K-wire exhibited greater stability at the fracture site and lower SIFs compared to those treated with a single screw.

The two treatment groups were evaluated under three different fracture mechanisms (K1, K2, K3). For each fracture type, stress intensity at the fracture line was measured and compared. In all three fracture types, the SIF was lower in the screw + K-wire group, indicating superior biomechanical stability. The negative value observed in the K3 fracture type was vectorial in nature and was attributable to the specific characteristics of the simulated fracture pattern.

Fracture type	Maximum SIF (1 screw only)	Maximum SIF (1 screw + 1 K-wire)
K1 (Opening mode)	30.579 MPa√m	24.408 MPa√m
K2 (Sliding mode)	36.809 MPa√m	33.932 MPa√m
K3 (Tearing mode)	–3.2462 MPa√m	–2.5114 MPa√m (Figure 5).

The lower SIF values observed in the K-wire-assisted group supported the positive biomechanical contribution of K-wire fixation in enhancing fracture stability, reducing stress concentration at the fracture site, and limiting rotational movements.

DISCUSSION

In the present study, we evaluated the effectiveness of using K-wires combined with screws for the surgical treatment of scaphoid fractures using clinical scoring and FEA and to determine its effect on fracture stability and patient outcomes. The main finding of this study was that supplementing a headless compression screw with a K-wire enhanced both clinical outcomes and biomechanical stability in the fixation of scaphoid fractures and nonunions. Ensuring optimal stability at the fracture site was essential for achieving successful union and minimizing complications such as delayed healing, malunion, or nonunion. Finite element analysis further demonstrated that the addition of a K-wire improved mechanical stability by reducing stress concentration at the fracture line.

Luria et al.[11] investigated the biomechanical stability of compression screws placed perpendicular to the fracture line in scaphoid fractures, emphasizing the importance of optimal screw positioning. Similarly, Acar et al.[12] used FEA to compare volar and dorsal screw fixation, demonstrating that volar fixation provided greater stability in flexion and neutral positions, while dorsal fixation was more effective in full extension. Building on these findings, our study applied volar or dorsal screw fixation depending on fracture localization and assessed the additional contribution of a parallel K-wire to stability using FEA. Our results indicate that K-wire augmentation enhances biomechanical stability when used alongside screw fixation.

A biomechanical study by Acar et al.[13] compared single-screw and double-screw fixation for scaphoid fractures. Their findings demonstrated that double-screw fixation significantly reduced fracture displacement in all planes and improved rotational stability. This aligns with our study results, which suggest that supplemental fixation with a K-wire can enhance stability when combined with a single screw. Similarly, Zhang et al.[14] described the "tripod technique" involving a compression screw and two anti-rotational K-wires for treating scaphoid waist nonunions. Their study found that while bone healing rates were similar in both the tripod and single-screw fixation groups, the tripod technique resulted in faster union, indicating its potential benefit in rotationally unstable nonunions. These findings further support the

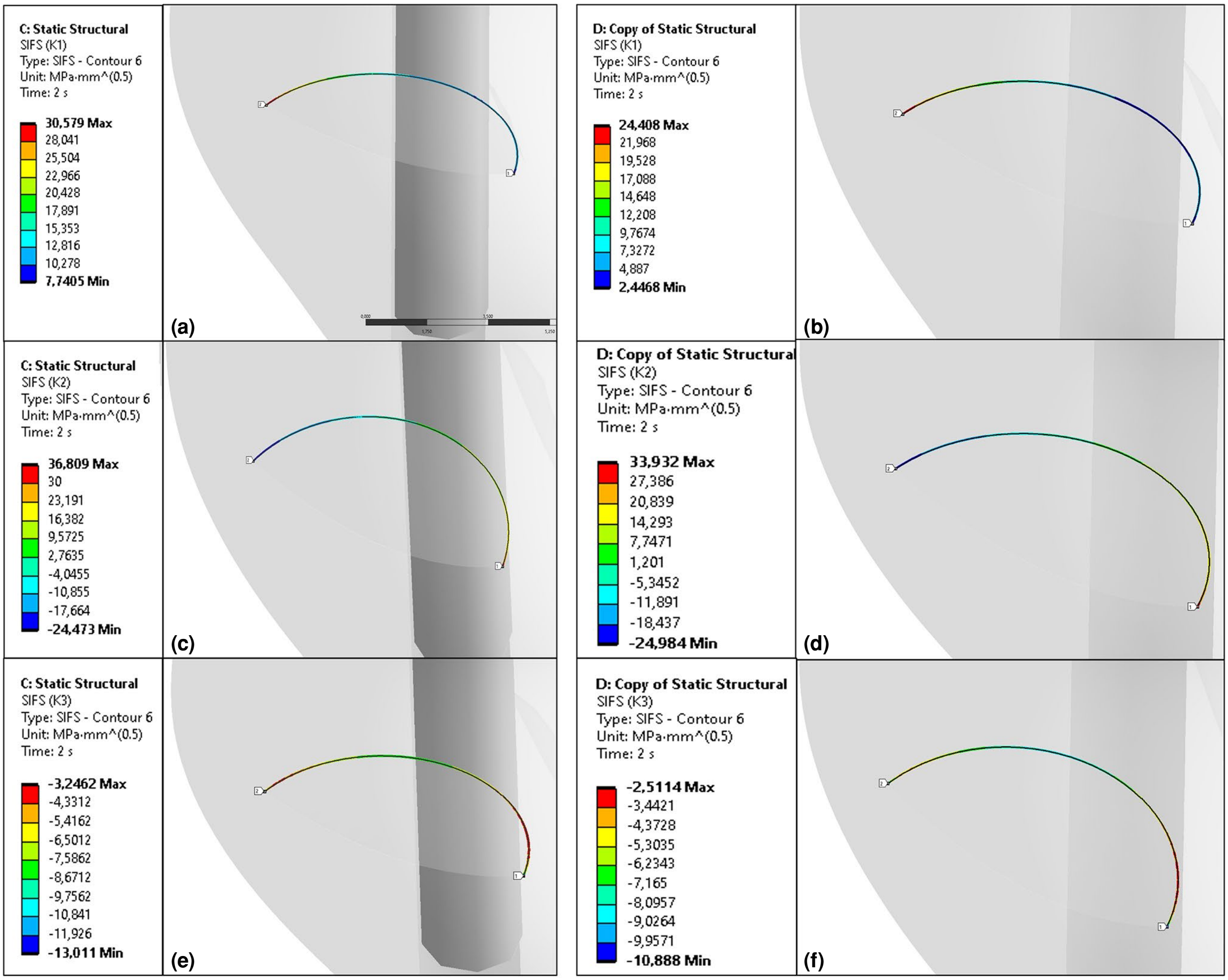

FIGURE 5. Maximum Stress Intensity Factor (SIF) values at the fracture line in models: **(a)** K1 with screw, **(b)** K1 with screw + K-wire, **(c)** K2 with screw, **(d)** K2 with screw + K-wire, **(e)** K3 with screw, and **(f)** K3 with screw + K-wire.

concept that additional fixation elements, such as K-wires, may improve mechanical stability and accelerate healing.

Clinical studies have investigated various surgical fixation techniques for scaphoid nonunions. Gurger et al.[15] reported high union rates with minimal complications using percutaneous volar screw fixation, highlighting its effectiveness as a minimally invasive approach. Similarly, Saint-Cyr et al.[16] demonstrated successful bone union and rapid functional recovery with dorsal percutaneous fixation. Atılgan et al.[17] compared percutaneous and open screw fixation, finding that while both techniques achieved similar union rates, open reduction resulted in faster healing and superior functional outcomes, making it a preferable option in cases requiring additional grafting or extensive stabilization. Additionally, Schormans et al.[18] reported statistically significant improvements in functional scores, grip strength, and range of motion with volar plate fixation combined with iliac crest autografting. In line with these findings, our study utilized autografts harvested from the distal radius or iliac crest in cases of nonunion to support bone healing in conjunction with fixation.

Furthermore, recent FEA studies have provided valuable insights into the biomechanical optimization of scaphoid fixation. Srivastav et al.[19] compared various fixation configurations and demonstrated that, in screw + K-wire and double K-wire fixations, the most stable constructs were achieved with parallel and divergent configurations, respectively. Similarly, our study confirmed that adding a parallel K-wire to screw fixation reduced the SIF at the fracture line, enhancing biomechanical stability. Unlike Srivastav et al.,[19] we also incorporated clinical assessments, revealing a strong correlation between FEA findings and improved clinical outcomes. These results further support the use of supplemental K-wire fixation in scaphoid fractures.

The findings obtained through FEA demonstrated that the addition of a supplementary K-wire to screw fixation reduced stress concentration at the fracture line. This configuration allows for a more balanced mechanical load distribution and promotes more stable contact between fracture fragments, thereby enhancing biomechanical stability. This increase in mechanical stability was also reflected at the clinical level. In our study, patients who underwent fixation with both a screw and a K-wire showed higher functional assessment scores, and a correlation was observed between these clinical outcomes and the FEA data. Accordingly, it was clearly demonstrated that lower stress concentration identified by FEA was associated with more favorable clinical scores. These findings suggest that the incorporation of a K-wire alongside a screw in scaphoid fixation improves mechanical stability, restricts rotational displacement, and is associated with superior clinical outcomes.

Nonetheless, this study has several limitations that should be explicitly acknowledged. First and foremost, its retrospective design introduces a risk of selection bias, which may affect the internal validity of the findings. Second, the relatively small sample size significantly limits the statistical power of the study and may weaken the reliability of the observed associations. Additionally, being conducted at a single center further restricts the generalizability of the results to broader populations. Finally, the relatively short follow-up period limits the ability to evaluate long-term clinical outcomes. To address these limitations and enhance the clinical relevance of future findings, further research should focus on multi-center, large-scale, prospective studies with extended follow-up periods.

In conclusion, incorporating a K-wire to screw fixation seems to enhance biomechanical stability and clinical outcomes in scaphoid fractures. These findings suggest that K-wire augmentation may be a beneficial strategy for improving healing and reducing postoperative discomfort.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept: E.A., İ.H.D.; Design: E.A.; Control/supervision: E.V.; Data collection and/or processing, writing the article: İ.H.D.; Analysis and/or interpretation: E.V., M.B.; Literature review: İ.H.D., Ş.Ç.; Critical review: E.A., Ş.Ç.; References and fundings: İ.H.D., U.B.; Materials: U.B., E.A.; Other (finite element analysis/software support): M.B.

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