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Research Article

Evaluation of Various Methods of Scaphocapitate Fixations in Kienbock Disease, A Finite Element Study

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Abstract

Introduction: Kienbock's disease is characterized by lunate osteonecrosis. The management of this disease poses a medical challenge, and the optimal surgical approach for its treatment has yet to be determined. Scaphocapitate fusion is one surgical option that can be considered for patients, as it has shown good functional outcomes. This study aimed to evaluate the most effective orthopedic devices for scaphocapitate fusion.

Methods: A wrist CT scan of a normal subject was used in this study to create a three-dimensional model using MIMICS, 3 Mat, Free CAD, and OpenSIM software. Scaphocapitate fusion was simulated in the model using one pin, one screw, two pins, two screws, and one pin and a screw. The displacement of the scaphoid bone, Von Mises stress of the scaphoid and capitate bones, and the orthopedic devices were calculated.

Results: The study revealed that the scaphoid bone could move 2.37 mm in the proximal direction in normal conditions. However, in scaphocapitate fusion, the bone only moved in the distal direction, with the least movement observed when using two pins (1.9 mm). The most effective control over mediolateral and vertical motions was achieved with two pins (2.38 mm vs. 1.35 mm) and one screw (5.60 mm vs. 3.13 mm), respectively. All methods significantly reduced the angular motion of the scaphoid bone.

Conclusion: While the various methods of scaphocapitate fusion show minimal differences, using one screw may be the most effective option for this operation.

Keywords: Kienbock's Disease, Scaphocapitate Fusion, Three-Dimensional Simulation.

Introduction

Kienbock's disease is a medical condition in which lunate osteonecrosis predisposes the wrist to fracture and arthritis [1]. Kienbock's disease is a rare disorder affecting about 0.3% of the general population. Despite its low prevalence, it can severely impact the patient's quality of life by interfering with their occupational activities [2, 3]. Kienbock's disease can manifest as a decreased range of motion in the wrist, painful grip, dorsal wrist edema, and tenderness [4]. Due to the variety of this condition, research regarding its etiology has been overlooked, but repeated micro trauma to the wrist and increased imposed load to the lunate bone have been speculated as the underlying causes of this disease [1, 5].

The choice of treatment in this condition heavily depends on the clinical presentation and radiographic stage of the disease and aims to prevent lunate collapse and wrist osteoarthritis. For instance, in late stages of Kienbock's disease without osteoarthritis, Limited Wrist Arthrodesis (LWA) and Proximal Row Carpectomy (PRC) can be considered proper surgical approaches to maintaining wrist motion [1]. Both scaphotrapeziotrapezoid and scaphocapitate arthrodesis are proposed for LWA [6]. However, due to the lack of evidence, the best approaches for these operations have yet to be determined.

Scaphocapitate fusion can significantly decrease pain and enhance the hand grip of patients with advanced

Kinbock's disease; however, this operation was found to limit the range of motion in the wrist joint in some previous studies [7, 8]. This operation has had a 24% complication rate, and 14% of the patients undergoing this surgery would need re-operation [9]. The most common complication was radio scaphoid osteoarthritis, possibly due to higher imposed force on this joint [9]. Thus, in light of the previously mentioned evidence, we used a three-dimensional modeling method to compare different therapeutic approaches and orthopedic devices in scaphocapitate fusion.

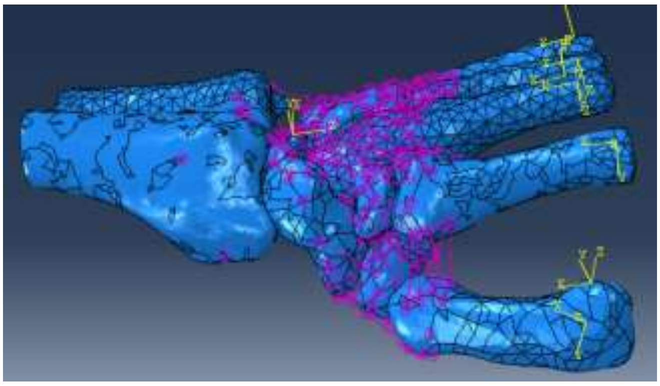

Figure 1: The standard model of the wrist joint in Abaqus software

Methods

In this study, the computed tomography scan of a typical wrist joint was obtained and used for three-dimensional modeling. The CT was obtained in 1.5 degrees of ulnar deviation with a slice thickness of 0.98 mm. The images were imported to MIMICS software (version 19.0, Materialize Company, Belgium) for three-dimensional modeling. The wrist joint, including the distal ends of the radius and ulna, the carpal bones, and the metacarpals, were incorporated in this model. Then, the model was exported to the 3Mat application (version 11.0, Materialise Company, Belgium) for reformatting into STL and contouring. Kienbock's disease was induced in this model, and then the surgical methods with screw and pin were conducted in 3 Mat.

The free CAD software was used to change the format of the bones from STL to STP (parts). The bone parts were exported to Abaqus for further analysis. The bones were assembled on each other. In the next step, the material properties of the bony models were applied to the model parts. The mechanical properties of the bones were obtained from the literature. The supportive ligaments of the wrist bones were modeled as spring elements. The stiffness of the ligaments was obtained from the literature [10]. The proximal ends of the radius and ulna were considered as boundary conditions. The extensor force of the wrist and finger joints was applied to the model using the Abaqus software. The force of the wrist joint extensor to move the wrist joint from flexion to extension was obtained from the authors' previous publications [11, 12]. Figures 1 and 2 show the normal and pathological models with pin fixation used in this study.

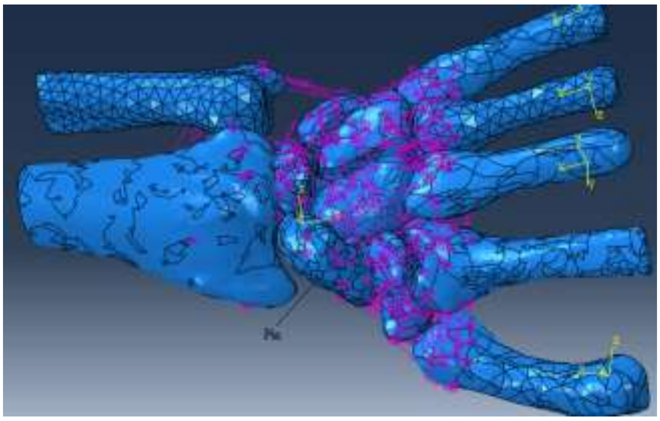

Figure 2: Pin fixation of Scaphocapitate joint

The maximum values of Von Mises stress of scaphoid and capitate bones, as well as scaphoid bone displacement in three directions and its angular motion relative to the horizontal plane, were measured in the following conditions:

A) Normal wrist

B) Pathological condition with pin fixation of scaphocapitate joint

C) Pathological condition with screw fixation of scaphocapitate joint

D) Pathological condition with double-pin fixation of scaphocapitate joint

E) Pathological condition with double-screw fixation of scaphocapitate joint

F) Pathological condition with simultaneous use of a pin and a screw for fixation of the scaphocapitate joint.

As this was a case study, no statistical analysis was performed, and only the values of the aforementioned parameters were reported.

Results

In this study, the CT scan images of a normal wrist were modeled, and the displacement of the scaphoid bone in distal proximal, mediolateral, and vertical directions was measured. The standard displacement of the scaphoid bone was 2.37, 2.38, and 5.80 mm in distal proximal (forward movement), mediolateral (to the ulnar side), and vertical (downward movement) directions. In contrast, in the pathological condition fixed with a pin, this bone moved 3.46 mm in the distal direction, 1.86 mm in the ulnar direction, and 3.73 mm in the downward direction. The minimum value of backward movement of the scaphoid bone was in fixation with two pins (1.90 mm) followed by the simultaneous use of a pin and a screw (2.02 mm) and then double-screw fixation (2.63 mm). The minimum values of vertical displacement of the scaphoid were achieved by the use of one screw (3.13 mm) and then by the use of two screws (3.50 mm).

The angular displacement of the scaphoid bone relative to the horizontal plane was also evaluated in this study. The minimum values of scaphoid angular motion were observed in double-screw fixation (54.5°) and the use of a pin and a screw (55.0°), respectively. The findings of the simulation regarding the direct and angular displacement of the scaphoid bone are summarized in Table 1.

Table 2 summarizes the stress applied to the scaphoid and capitate bones in various conditions. In the normal condition, the applied stresses on the scaphoid and capitate bones were 2.28×102 and 2.65×102 MPas, respectively. The stress applied on the scaphoid and capitate bones increased significantly in various methods of scaphoid fixation.

Table 1: Displacement of scaphoid bone in wrist motion in normal and in fixation with various approaches

Fixation methods	Distal proximal displacement (mm)	Mediolateral displacement (mm)	Vertical displacement (mm)	Angular displacement (degrees)
Normal condition	2.37	2.38	-5.6	75.2
One pin	-3.46	1.86	-3.73	56.5
One screw	-3.27	1.49	-3.13	58.5
Two pins	-1.9	1.35	-4.10	58.6
Two screws	-2.63	1.89	-3.50	54.5
One pin and one screw	-2.02	1.77	-4.60	55

Table 2: The stress applied on the scaphoid and capitate in normal conditions and in fixation with various methods

Fixation method	Scaphoid stress (MPas)	Capitate stress (MPas)	Pin stress (MPas)	Screw stress (MPas)
Normal condition	2.28×10^2	2.55×10^2	-	-
One pin	1.50×10^3	6.40×10^2	9.60×10^2	-
One screw	5.22×10^2	5.22×10^2	-	3.00×10^3
Two pins	1.07×10^3	7.10×10^2	7.10×10^2 8.80×10^2	-
Two screws	3.38×10^2	1.19×10^3	-	2.06×10^3 2.75×10^3
One pin and one screw	8.50×10^2	4.16×10^2	1.17×10^3	1.50×10^3

Discussion

In this study, a three-dimensional simulation was used to assess the efficacy of and postoperative results of scaphocapitate fusion using one or two pins and/or screws. The wrist joints' mechanical properties, including the capitate bone's linear displacement in three directions and its angular motion, were compared using different fixation methods. Then, the stress applied on the scaphoid and capitate bones and orthopedic devices were compared in these surgical approaches.

In these simulations, we found that the displacement of the scaphoid bone in normal conditions would be 2.37 mm to the proximal, while in every method of fixation, the proximal motion of the scaphoid was limited, and this bone could only move in backward (distal) direction. The best control over scaphoid movement in the proximal-distal direction belonged to double-pin-fixation of the scaphocapitate joint, while the minimal control belonged to fixation using one pin or one screw, Table 1. Regarding mediolateral and vertical movements of the scaphoid bone, all fixation methods exerted a higher control on movement in these planes compared to the normal condition. However, the most significant limitation in mediolateral displacement belonged to double pin fixation and fixation with a single screw, and for vertical motion, single screw fixation was superior, Table 1. After fixing the scaphocapitate joint, the angular motion of the scaphoid bone was less than the expected condition, and the surgical methods did not differ significantly in this parameter, Table 1. Limitation of the angular motion of the scaphoid bone in scaphocapitate fusion methods might indicate that the wrist flexion or extension would be limited in this operation. This finding is in line with the findings of previous studies that found that postoperative flexion and extension of the wrist would reach 54% and 74% of the non-affected contralateral side [13].

Compared to the surgical methods with different fixative instruments, the least amount of Von Mises stress was applied to the scaphoid bone in double-screw and single-screw fixation methods, Table 2. In comparison to the Von Mises stress on the capitate bone, the simultaneous use of a pin and a screw was superior, followed by using a single screw in fixing the scaphocapitate bone. When the sum of the Von Mises stress is being considered, single screw-fixation of the joint significantly outperforms the other methods.

In a study by Collon et al., the authors performed scaphocapitate fusion on 17 patients. They found that this operation effectively reduced the patients' pain and maintained their wrist range of motion and hand grip. They used two headless screws in most of their cases and showed that failure of scaphocapitate fusion occurred in four patients, but it was not clear if those wrists were fixed with screws or Kirschner wires. However, they found that this fixation method was comparable to scaphotrapeziotrapezoid fixation in cases of Kienbock's disease [13]. The findings of our study are in conjunction with the study of Collon et al., who assessed the functional state of the patients after the operation, indicating the efficacy of this method of treatment.

A recent review article by Bouri et al. showed that scaphocapitate fusion could significantly decrease wrist pain, decrease radial deviation, increase grip strength, enhance joint functioning, and decrease carpal height ratio. However, the wrist flexion, extension, and ulnar deviation changes were not statistically significant. However, the heterogeneity in the results of the studies was high, possibly due to various surgical techniques performed in different studies [9]. The authors concluded that this operation efficiently treated advanced Kienbock's disease despite its controversial results. The current study elucidated the best surgical approach for scaphocapitate fusion, which can help improve postoperative outcomes further.

Not everything about scaphocapitate fusion is positive since about 24% of the patients are expected to experience some complications, and about 14% of the patients will need revision surgery [14-16]. The most important complication in this operation is wrist osteoarthritis, which is associated with more displacement of the scaphoid bone [9]. Although the scaphoid bone in regular join moves more quickly than the fused scaphoid bone, since the movement in the fused bone is in the opposite direction in the anteroposterior plane, without proper anatomic configuration, this complication can occur [17]. Among different fixation methods, using two pins or one screw showed the best results, and using one pin was associated with the highest displacement of the scaphoid bone, predisposing the wrist to a higher risk of osteoarthritis.

There is a limitation associated with this study. The main limitation was the small number of subjects.

Therefore, it is recommended that a greater number of subjects be evaluated in future studies. Moreover, it is recommended that the output of this study be evaluated on the patients, and some parameters such as pain and quality of life will also be evaluated.

Conclusion

In this study, the best surgical approach for scaphocapitate fusion was assessed using a three-dimensional simulation, and we found that using one screw for this purpose shows better results.

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Conflict of Interest Disclosures

No conflict of interest to be reported.

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Authors' Contributions

HN supervised the project

MTK supervised the project, created 3d models, run the models and checked the final draft of the paper.

FS responsible for paper writing and data collection.

Ethical Statement

An ethical approval was obtained from Shiraz University of Medical Sciences, ethical committee.

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