Original

Evaluation of Various Methods of Lunotriquetral Stabilization Surgical Producers, A Finite Element Analysis

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ABSTRACT

Background: Patients with Lunotriquetral Interosseous Ligament (LTIL) injuries often experience wrist pain and carpal instability, resulting in challenging treatment. The optimal surgical approach has to be determined for addressing this condition.

Objective: The current study aimed to assess the postoperative outcomes of orthopedic devices in lunotriquetral fixation using a 3D model.

Material and Methods: This computer simulation study aimed to develop a three-dimensional model of a normal wrist joint. The study then simulated LTIL tears and compared three surgical methods for fusing the lunate and triquetrum bones using a pin, a screw, and a combination of both.

Results: Based on normal mechanistic behavior in terms of anteroposterior and mediolateral displacement of the lunate bone, the results are presented. However, the use of pin-fixation is significantly superior to the other methods with a displacement of 1.65 and 1.47 mm in fixation versus 0.32 and 0.64 mm in normal anatomy. This approach also significantly decreased the stress on the lunate bone and showed the least stress on the orthopedic device compared to other surgical approaches. For the triquetrum bone, pin fixation proved superior in controlling anteroposterior and vertical motions. This method also imposed significantly less stress on the triquetrum compared to using a screw or double instrumentation.

Conclusion: Lunotriquetral fusion can be achieved using a pin, which provides better results than fusion with a screw or the combined use of a screw and pin.

Keywords

Lunotriquetral Fusion; Lunate Bone; Triquetrum Bone; Pin; Orthopedic Fixation Devices; Bone Screw; Wrist

Introduction

The Lunotriquetral Interosseus Ligament (LTIL) is one of the most important ligaments in maintaining carpal stability [1]. Injury to ligaments supporting the lunotriquetral joint is the second most common cause of carpal instability which mostly affects young athletes [2]. The anatomic configuration of LTIL is C-shaped consisting of volar (main part), dorsal, and membranous components. LTIL transaction can lead to wrist instability through lunate flexion [1-3]. Although LTIL injuries are rare, they can occur following trauma to the dorsal part of the wrist when in a flexed position [4]. These injuries may present with

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tenderness on the ulnar side of the wrist, reduced grip strength, pain during ulnar deviation, or as vaguely described dorsal wrist pain in chronic cases. In physical examination, the triquetrum compression, Kleinman, lunotriquetral ballottement, and Reagan tests can be positive in cases of LTIL injury [1]. The diagnosis is usually overlooked due to normal radiographic images; however, the injuries can be detected in magnetic resonance arthrography [5].

Since the diagnosis of this disease is dilemmatic, improper management of the condition is commonly encountered, leading to osteoarthritis and difficulty in performing daily activities [6]. If the wrist is generally stable, conservative management with immobilization can be a reasonable option. Corticosteroid injections are indicated in cases of persistent pain. Operative management should be considered if the joint is unstable, and the surgical options for this condition range from arthroscopic repair, closed reduction, and fixation using Kirschner wires, pins, or screws and capsulodesis [7]. However, no studies have compared the internal fixation of this joint using different orthopedic instruments in various configurations, likely due to the variability of this condition. The fixation of the lunotriquetral joint leads to high rates of complication. Arthroscopy management of LTIL injuries is the gold standard of treatment in developed countries. However, determining the best approach to prevent postoperative complications, such as osteoarthritis and malunion/nonunion, is crucial, particularly in resource-limited settings, in which proper surgical instruments and expertise may be lacking [8]. Consequently, the current study aimed to assess pin- and screw-fixation of lunotriquetral joints with different instrument directions using a three-dimensional model for better postoperative outcomes.

Material and Methods

In this computer simulation study, the Computed Tomography (CT) scan of the wrist joint in a normal subject was used to create a 3D model of the wrist joint. The CT scan (the 1.5 ulnar deviation with 0.98 mm thickness for the slices) of the wrist joint was exported to the Mimics software (Version 19, Materialise Company, Belgium) to create a 3D model, and the model of all bones in the wrist joint (the carpals, meta-carpals, ulnar, and radius) was produced. The 3D model of wrist joint bones was exported to 3 Mat software (version 11, Materialise Company, Belgium) for smoothing, re-meshing, and changing the format into STL. Moreover, pin fixation, screw fixation, and both fixation with screw and pin were done. It is important to note that in this study, the lunotriquetrum was fixed following the rupture of the Lunotriquetral Interosseous Ligament (LTIL) (Figure 1). The wrist joint complex bones were first exported to free CAD software to convert the models from STL format to parts. The final models were exported to Abaqus for further analysis, where the 3D models of the wrist joints were assembled. In the next step, the 3D models of the wrist joint bones were meshed, and the mechanical properties of the bones were applied to the structure [9-12]. The supporting ligaments were modeled of spring elements. The stiffness of the supporting ligaments was obtained from the literature [11, 12]. The force of the wrist joint extensors was applied to the model in Abaqus software. The force of the wrist and finger extensors was obtained from the output of OpenSIM software [13]. The distal end of the radius and ulnar was selected as a boundary condition in Abaqus software. Some parameters, such as the Maximum Value of Von Miss stress (MPAS), displacement of the lunate, and triquetrum bones in anteroposterior, mediolateral, and vertical directions, and angular displacement of the lunate bone were evaluated relative to the horizontal plane. The following conditions were assessed: normal condition with intact lunotriquetral interosseous ligament, pathological conditions with ruptured LTIL, pin fixation, screw fixation, and pin and screw fixation. This study was approved by the Ethics Committee of Shiraz University of Medical Sciences, Shiraz, Iran.

Results

This study compared the results of three different surgical methods for lunotriquetral

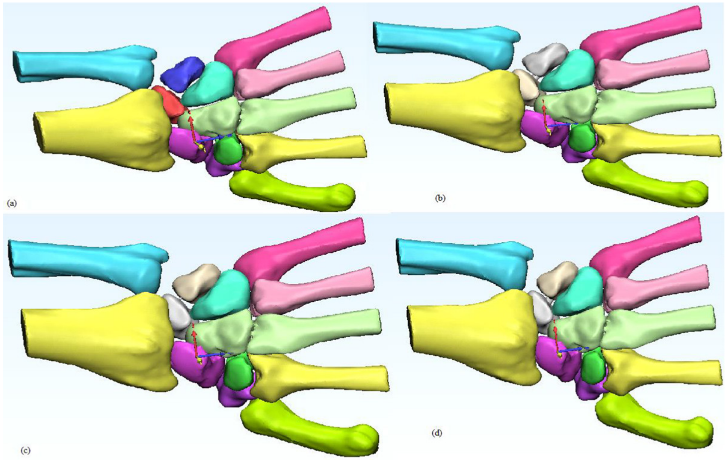

Figure 1: The models used in this study, (**a**) Normal model, (**b**) fixation with screw, (**c**) fixation with pin, (**d**) fixation with pin and screw

fusion: using a pin, a screw, or both a pin and a screw. The current study also looked at how much the bones moved after surgery and the amount of stress placed on them, and compared these results to normal and abnormal (pathological) wrists to understand how well each surgical method worked.

The post-operative outcomes of lunotriquetral fusion regarding the lunate bone are summarized in Table 1. In normal conditions, the lunate bone was displaced for 0.32, 0.64, and 5.00 mm in the anteroposterior, mediolateral, and vertical planes. When the LTIL was completely torn, the lunate bone moved more freely from side to side, but its up-and-down movement was limited to about 4.10 millimeters. In the three surgical methods for lunotriquetral fusion, pin-fixation showed the least mobility of this bone in the anteroposterior direction (1.65 mm), which was the closest to the normal anatomic condition, with a significant difference among the three options. Moreover, the fixation of the lunotriquetral joint using a pin (1.47 mm) showed more resemblance to the normal condition compared to the screw fixation and double-instrument fixation (3.97 mm and 3.10 mm, respectively). The amount that the lunate bone moved up and down was very similar after the three different fusion surgeries. None of the methods were significantly better or worse than the others, and all were close to the normal movement of about 5 millimeters.

The stress imposed on the lunate bone was also assessed in the current study. In the normal condition, 453 MPas was imposed to the lunate bone, which was increased to 513 MPas in total LTIL tear. However, the use of a pin in the lunotriquetral fusion decreased the stress significantly (360 MPas); screw-fixation and double-instrument operation significantly increased the stress on the lunate bone predisposing the joint to arthrosis. Moreover, the pin-fixation method showed the least amount of stress imposed on the surgical instrument. As for the angular motion of the lunate bone after the surgery, the angular motion was significantly limited in all three methods. However, the use of two instruments was superior to the other approaches, which might provide the patients with more range of motion.

Table 2 presents the mechanistic parameters of the triquetrum bone after its fixation with the lunate bone in different surgical approaches. The triquetrum bone could move for 3.07 mm, 0.94 mm, and 4.60 mm in the anteroposterior, mediolateral, and vertical directions, respectively. When the LTIL was completely torn, the bone could move in the mediolateral plane more freely (1.55 mm). However, its motion in anteroposterior and vertical directions was rather limited (2.24 mm and 3.99 mm, respectively). Screw-fixation and double-instruments significantly decreased the triquetral motion in the anteroposterior aspect (0.20 mm and 1.25 mm, respectively), but fusion with a pin was relatively similar to the normal individual in this respect (3.27 mm). Fusion of the lunate and triquetrum bones increased the triquetral motion in the mediolateral direction even further than the total pathologic condition, and the difference was not clinically significant. Pin-fixation also showed superior results in the vertical motion of the triquetrum bone compared to other surgical approaches. The maximal stress imposed on the triquetrum bone was significantly lower in the pin-fixation method (109 MPas) compared to the screw-fixation (701 MPas) and double instrumentation (867 MPas).

Discussion

In this study, after 3D modeling of a normal wrist joint, the lunotriquetral ligament was completely torn to induce wrist instability. Then, in the model, lunotriquetral fixation was achieved using a pin, a screw, and one pin along with one screw. The current study measured how much the lunate and triquetrum bones moved, the amount of force on each bone, and how much the lunate bone rotated. We also measured the force on the pins and screws used in each surgery.

The amount the lunate bone movement from front to back, showing that tearing the ligament didn't affect its movement, but fixing the joint with surgery actually caused it to move more than normal or injured wrists. A pin and a screw led to the most movement in this direction.

As for the side-to-side movement of the lunate bone, using a screw or a pin and a screw together caused the bone to move more than just using a pin. However, the amount of bone moved up and down, and all three surgical methods were similar to normal wrists. Also, none of the methods limited the bone's rotation, and the force on the implants and bone was low. Based on these results, fixing the lunotriquetral ligament injury

Table 1: The displacement of lunate bone, stress on lunate bone, angle of lunate bone displacement, and maximum value of von miss stress in different conditions

	Anteroposterior displacement (mm)	Mediolateral displacement (mm)	Vertical displacement (mm)	Von miss stress (MPas)	Angular displacement (°)	Von miss stress on implant (MPas)
Normal	0.32	0.64	5.00	453.0	16.0	-
Pathological	0.32	1.26	4.10	513.0	11.0	-
Pin-fixation	1.65	1.47	5.28	360.0	7.0	3340
Screw-fixation	1.88	3.97	5.00	859.0	3.5	3600
Pin and screw-fixation	2.00	3.10	4.57	860.0	9.0	Pin: 867 Screw: 3400

Table 2: The displacement of triquetrum bone in three directions (in mm) and maximum value of Von Miss stress in normal, pathological, and various methods of fixations

	Anteroposterior displacement (mm)	Mediolateral displacement (mm)	Vertical displacement (mm)	Von Miss stress (MPas)
Normal	3.07	0.94	4.60	103.3
Pathological	2.24	1.55	3.99	103.3
Pin-fixation	3.27	2.90	2.80	109.2
Screw-fixation	0.20	3.12	0.54	701.0
Pin and screw-fixation	1.25	2.68	0.36	867.0

with just a pin seems to be the best option when focusing on the lunate bone's health (Table 1).

When considering the triquetrum bone, pin-fixation of the joint mostly resembles the normal anatomy in the anteroposterior displacement of the bone, while screw-fixation significantly limits the anteroposterior motion of the triquetrum bone. There wasn't a big difference in how much the triquetrum bone moved from side to side with the three surgical methods, but a pin and screw together was slightly better. However, using a pin alone was significantly better at preventing up-and-down movement of the triquetrum bone, and it also put the least amount of stress on the implant (Table 2).

In a study by Nelson et al. [8] the authors compared lunotriquetral using Kirschner wires and concomitant use of K-wires and screws. They found that in cases of using K-wires alone 60% of the procedures ended in proper fusion of the bones; in the patients who needed a revision arthrodesis, the fusion was completely successful though. In cases of screws in lunotriquetral fusion, the rate of success was 91%. In this study, the long-term fusion of the bones was not assessed, and only the results of surgery immediately after the operation were evaluated; however, since non-union has a multifactorial etiology consisting of post-op bone motility and stress, finding the best approach in this matter can predict the long-term effects as well.

Further, Senwald et al. [14] performed lunotriquetral fusion on 23 patients using screws and showed that about 57% developed pseudoarthrosis; however, the mean period of follow-up of the patients was not available. Accordingly, lunotriquetral fusion might not be clinically acceptable due to high rates of complication. In the current study, lunotriquetral fixation using screws was relatively inferior to fixation with a pin or concomitant use of a pin and a screw. Thus, lunotriquetral fixation with a revised method using pins might show clinical potential for the treatment of patients with LTIL injury.

In another study by Vandesande, [15], 44.8% of the patients undergoing lunotriquetral fusion experienced nonunion. The range of motion of the patients who had non-union and successful operations did not differ. With regard to different surgical methods, patients who underwent screw-fixation had higher fusion rates compared to K-wire fixation. The study did not include any patients who had undergone lunotriquetral fusion using pins. Given our findings that pin fixation yielded better postoperative outcomes compared to screw fixation, this surgical technique may warrant further investigation for LTIL injuries.

Lunotriquetral fusion was performed with the addition of a cancellous bone graft [16]. This approach resulted in impressive outcomes, including over 80% pain reduction and a complete fusion rate within 50 days.

More novel methods, mostly using arthroscopic approaches, have been introduced for better management of LTIL injuries. For example, dorsal ligamentocapsulodes was proposed by Özçelik, which resulted in a pain-free status in most of the patients [17]. In low-resource settings, where access to skilled surgeons and advanced equipment is limited, exploring effective traditional surgical methods is crucial. Furthermore, in well-resourced environments, comparing pin fixation to arthroscopic techniques in future studies would be beneficial. It's important to note that 3D modeling doesn't fully capture the complexities of real-world surgeries, including potential complications. Therefore, additional clinical trials are necessary for a comprehensive understanding of this issue.

Conclusion

Lunotriquetral fusion for lunotriquetral interosseous ligament injuries can be achieved through various surgical approaches. However, a pin for bone fixation can be superior to screws or double instrumentation, particularly in low-resource setting.

Authors' Contribution

MA. Mahdiyar, MT. karimi participated in writing process. The first author in H. Namazi. MT. Karimi wrote the method and materials and did the data analysis. Both MA. Mahdiyar and HN. Namazi collected data. H. Namazi wrote the result. All the authors read, modified, and

approved the final version of the manuscript.

Ethical Approval

This study has been approved by the Committee of ethics in Biomedical Studies of Shiraz University of Medical Sciences with ethical code: IR.SUMS.MED.REC.1402.295.

Informed Consent

This article does not involve any human or animal participants and is based on existing literature or research. However, the CT scan which were used for computer simulation was obtained from PACS image system.

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Conflict of Interest

None

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