Post-surgery stability of Scaphoid fractures under different fixation configurations: A Finite Element Analysis

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1. Introduction

1.1 Anatomy of the Scaphoid bone

Scaphoid is one of the eight carpal bones in the wrist, it sits below the thumb and is shaped like a kidney bean. Blood supply to the distal pole is **adequate** but is **insufficient** to the waist and the distal pole.

Figure 1. Scaphoid bone

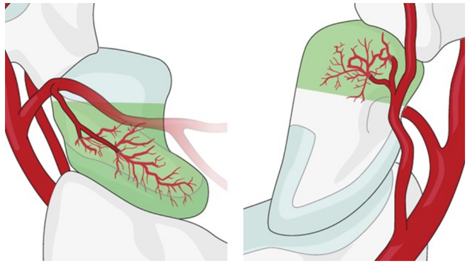


Figure 2. Blood supply

1.2 Fractures in the Scaphoid bone

Scaphoid is the most frequently fractured carpal bone, accounting for about 70% of the carpal bone fractures.

Cause: Fall onto an outstretched hand.

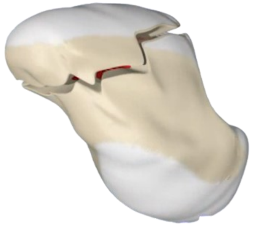


Figure 3. Distal pole fracture 20% cases

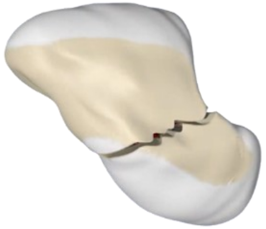


Figure 4. Waist fracture **70% cases**

Figure 5. Proximal pole fracture 10% cases

1. Introduction contd.

1.3 Surgical treatment of Scaphoid fractures

Fractures at the waist or proximal pole are treated by surgery to **realign and stabilize** the fracture, giving it a better chance to heal.

The two implants used for surgery are:

1. Kirschner wire (K-wire)
2. Herbert screw

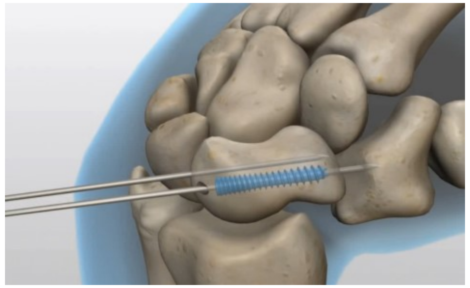


Figure 6. Surgery for Scaphoid fractures

1.4 CAD modelling and specimen

CAD model of Scaphoid is constructed from CT scan of hands. CAD model of implants are constructed with precise and accurate measurement of specimen.

Figure 7. CAD model of Scaphoid bone

Figure 8. CAD model of implants

2. Methods

2.1 Impact force calculation

Two cases of Scaphoid fracture are considered:

1. Person slipping while walking
   Calculated impact force (F) = **1600 N**
2. Person falling from a stationary motorbike
   Calculated impact force (F) = **4000 N**

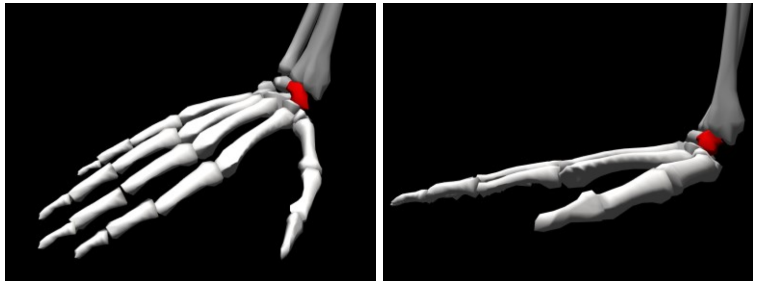


Figure 9. OpenSim model to study the force transmission, upon fall onto an outstretched hand

2.2 Fracture location in Scaphoid using FEA

The most probable site of fracture in Scaphoid is located using FEA with impact loads varying between 1600 N to 4000 N.

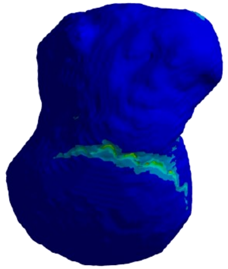


Figure 10. Max. stress results from FEA

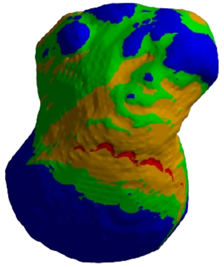


Figure 11. FOS results from FEA

2. Methods contd.

2.3 Surgery replication in CAD model assemblies

The study of locating fractures in Scaphoid using FEA established that Scaphoid waist fractures are the most probable. Subsequently, three common types of surgical treatment for Scaphoid waist fracture are replicated in CAD.

Salient features of the CAD model assemblies:

1. The fracture is created at the exact location found in Section 2.2
2. Surgeon first inserts the K-wire and then drills in the Herbert screw. Thus, the bone volume inside the Herbert screw is hollow in the CAD models.

Scenario 1:
Single screw surgery

6 cases:
1. Random 1
2. Random 2
3. Random 3
4. Random 4
5. Random 5
6. Random 6

Scenario 2:
Screw and wire surgery

6 cases:
1. **Parallel**
2. Random 1
3. Random 2
4. Random 3
5. **Converge**
6. **Diverge**

Scenario 3:
Two wire surgery

6 cases:
1. **Parallel**
2. Random 1
3. Random 2
4. Random 3
5. **Converge**
6. **Diverge**

Figure 12. CAD model of single screw surgery

Figure 13. CAD model of screw and wire surgery

Figure 14. CAD model of two wire surgery

2. Methods contd.

2.4 Finite Element Analysis (FEA) for post-surgery stability

A total of 32 static structural finite element models are constructed in ANSYS:

1. Geometry
   - i. 6 cases of single screw surgery
   - ii. 6 cases of screw and wire surgery
   - iii. 6 cases of two wire surgery
2. Material properties
   - i. Scaphoid bone
   - ii. K-wire (Stainless Steel)
   - iii. Herbert screw (Titanium)
3. Contacts
   1. Frictional contact between two parts of fractured bone ($\mu = 0.4$)
   2. Bonded contact between all other parts
4. Loads
   - **i. Case 1**: Tensile load (**100 N**) + Bolt pre-tension (**20 N**)
   - **ii. Case 2**: Compressive load (**300 N**) + Bolt pre-tension (**20 N**)
5. Boundary conditions
   - i. Fixed support at contact with Radius bone
   - ii. Fixed support at contact with Capitate bone

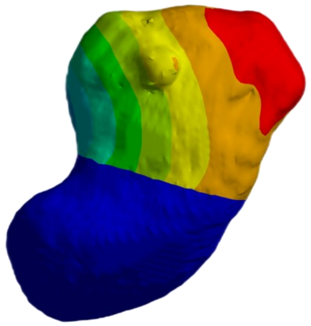


Figure 15. Max. Total Deformation in single screw surgery

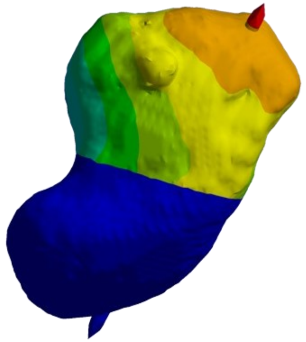


Figure 16. Max. Total Deformation in screw and wire surgery

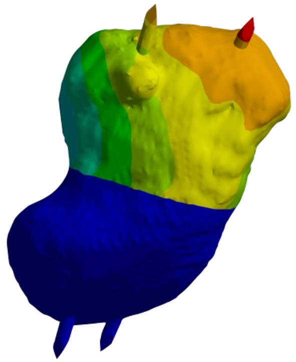
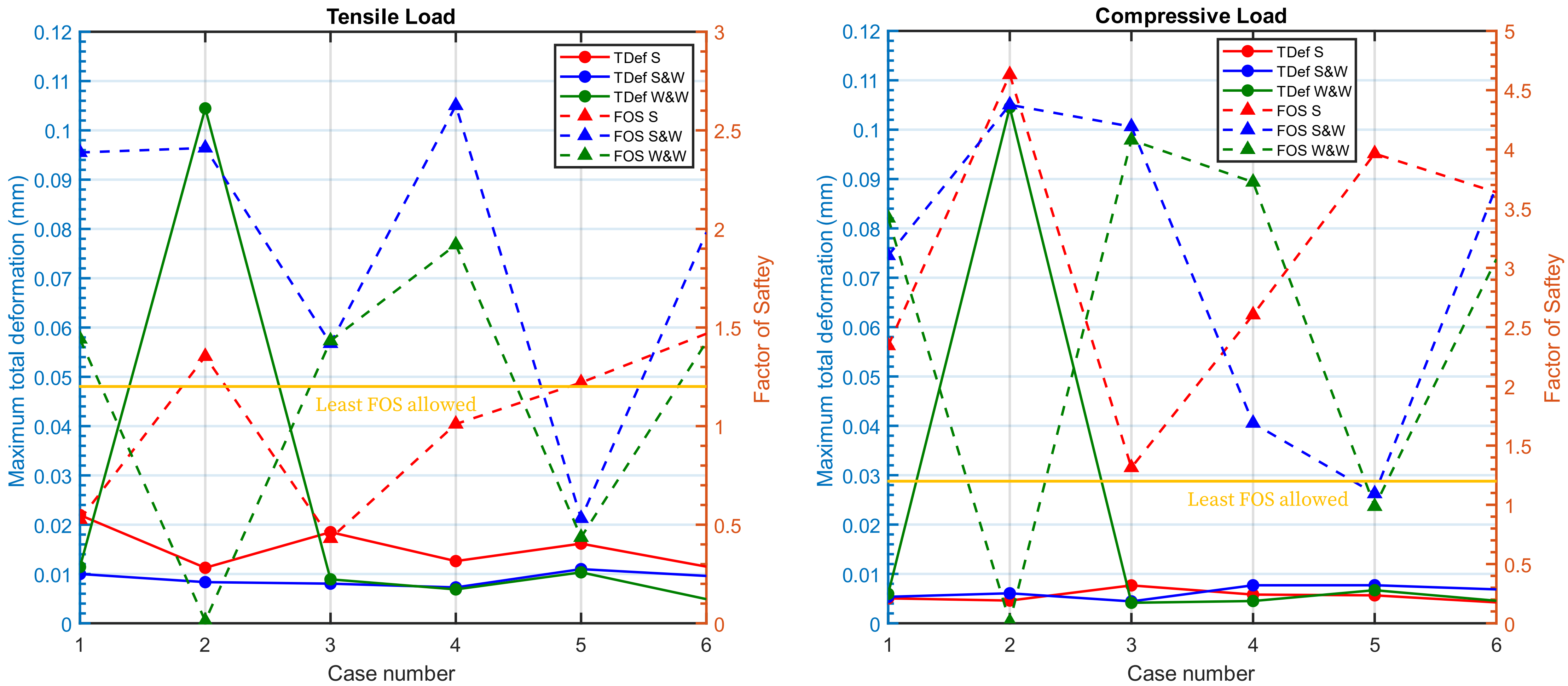


Figure 17. Max. Total Deformation in two wire surgery

3. Results and Conclusions

The following two results are extracted from the 32 cases of Finite Element Analysis in ANSYS and are plotted in the two graphs below:

1. Maximum Total Deformation (displacement) between the two separate parts of the fractured Scaphoid bone
2. Factor of Safety of implants (K-wire & Herbert screw)



TDef = Maximum total deformation; FOS = Factor of Safety; S = Screw; S&W = Screw and Wire; W&W = Wire and Wire

Figure 18. All FEA results of maximum total deformation and factor of safety for (1) single screw, (2) screw & wire and (3) two wire surgical treatment of scaphoid bone fractures

Conclusion: **Screw and wire** surgical treatment with **parallel or divergent** fixations provides the maximum post-surgery stability for scaphoid fractures.