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Original Article

Angulated versus parallel headless cannulated screw fixation for type 1 capitellum fracture: A finite element study

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Abstract

Aim: The unique shape and vascularization make capitellar fractures challenging to treat. In such cases, screw inclination is crucial to achieve stable fixation. In the present study, we aimed to evaluate the mechanical outcome of the different fixation angles formed by headless cannulated screws for treatment of type 1 capitellum fracture and compared interfragmentary displacement (IFD) using finite element analysis (FEA).

Material and Methods: In our study, three-dimensional finite element stress analysis was applied using the isotropic materials and static linear analysis. Stochastic screw inclination scenarios (Case 1, Case 2, Case 3, and Case 4) were generated, and perpendicular application of loads were simulated with magnitudes between 50 and 300 N on the elbow at angulations from 0º to 145º. The IFD in the four different screw inclination pairs were listed in the ANSYS general end processor. Relative IFD was calculated by measuring the total displacements in the X/Y/Z planes from 16 different points.

Results: According to the modeling, the magnitude of IFD was significantly different in terms of the force and the case factors under four altered forces. Analysis of displacement exhibited a significant difference in the force values of '100N/200N/300N' and in the screw inclinations of Case 2 only. Although the interaction effect between the Force*Case was observed to be low, the most noticeable results were obtained from the "300N*Case 2." pair compared to the others ($p<0.05$).

Conclusion: Screws used for fracture fixation must maintain an anatomical correction, until it heals. Following a complex trauma such as a capitellar fracture, the elbow joint needs a stable fixation and early mobilization. Our FEA results suggest that the fixation via angled screws can achieve a more stable configuration than the paralleled ones.

Keywords: Finite element analysis; headless cannulated screws; interfragmentary displacement; Type 1 capitellum fracture

INTRODUCTION

The capitellum is a rounded, smooth, enlarged lateral end of the humerus, which makes a distal lateral articular portion of an elbow joint, with a radial head. It is directed distally and anteriorly at an angle of 30° to the long axis of the humerus. Its center of rotation is located at 12 to 15 mm anteriorly to the humeral shaft axis (1,2). Anteriorly, the capitellum is covered with a 2-mm thick hyaline cartilage and, from posteriorly, it has a main intraosseous blood supply originating from the anastomosis of the radial collateral arteries of the profound brachial and the radial recurrent artery (3). This unique shape and vascularization make capitellar fractures challenging to treat.

The incidence of elbow fractures involving only the capitellum is approximately 1% (4). The capitellar fracture mechanism is very similar to the mechanism of radial head fractures, as it is caused by vertical shear stress transmitted from the head of the radius due to falling from a height in an extension or semi-flexion position. In the literature, various treatment methods have been described. Closed reduction, splinting, and bracing are options for a conservative treatment. Fragment excision, arthroscopic-assisted fixation, cancellous lag screws, Herbert screws, and headless cannulated screws are the current options for an open reduction and internal fixation (5-9).

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To the best of our knowledge, there is no clinical or in vitro study related to screw inclination effects on capitellum fracture fixation in the literature. In the present study, we hypothesized that angled screw fixation would provide a more stable fixation than the parallel one when used for type 1 capitellar fractures. We, therefore, aimed to evaluate the relationship between screws fixation angles and interfragmentary displacement (IFD) of type 1 capitellum fractures using the finite element analysis (FEA).

MATERIAL and METHODS

This study was conducted Bursa Uludag University between 2018 and 2019. Since our study is a finite element analysis study, it does not require ethical committee approval. In this study, a series of numerical simulations were performed to investigate the biomechanical behavior of capitellum fractures in randomly pre-determined different screw inclination scenarios including Case 1, Case 2, Case 3, and Case 4 using the ANSYS Workbench software (version 16.0, ANSYS, Canonsburg, PA, USA). The relative IFD was calculated by measuring the total displacements in the X/Y/Z planes from 16 different planes.

Design parameters and functional requirements

The geometrical data of an intact capitellum was obtained using computed tomography (CT) scan of humerus composite bone model . (Sawbone. Europe, Malmö, Sweden). The geometry of screws was modelled using the SolidWorks® (Dassault Systèmes, Waltham, MA, US) The 3.5-mm headless cannulated screws (Acumed Inc., Beaverton, OR, USA) were modeled and employed to simulate capitellum type 1 fracture fixation. The three-dimensional (3D) computer-aided design (CAD) model of the screws is illustrated in Figure 1.

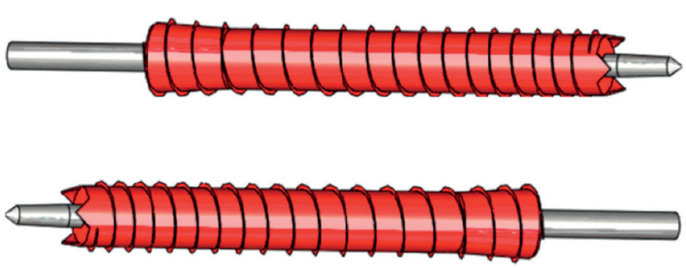

Figure 1. A three-dimensional computer-aided design model of the headless cannulated screws

Finite element model

Material properties assignment

The CAD model of the capitellum (distal humerus) and screws were imported into the ANSYS Workbench software for pre-processing environment to create the finite element model required to investigate the biomechanical behavior of capitellum fractures, under different screw inclinations. The bone model was assumed to be homogeneous and isotropic with linear elastic properties. Similar FEA studies conducted regarding bone modeling are available in the literature (10-13). The material properties of the cortical bone, cancellous bone, and the screws are summarized in Table 1.

Table 1. Material properties

	Cortical Bone	Cancellous Bone	Screw	Unit
Elastic Modulus	$12x10^9$	$0.8x10^9$	$210x10^9$	N/m^2
Poisson Ratio	0.3	0.3	0.3	-

Meshing

This primary data, which was generated in .stl format, was imported to the HyperMesh® (Altair Engineering, Inc., MI, USA) for geometric editing and mesh discretization. The cortical bone thickness was divided into three parts along the length and measured by CT scans. The thickness of the epiphysis was set as 2.5 mm, while the diaphysis was 6.5 mm. The small error of this approximation was within the limits of the scanner for the measurement of the real bones from different patients.

The meshing process was implemented using the HyperMesh® 11.0 Software (Altair Engineering, Inc., MI, USA). The hexahedral mesh structure was generated with a size of 1 mm, which was adequate for performing the surgery simulation in FEA (Figure 2). The mesh structure consisted of approximately 116,625 elements and 372,795 nodes. The numbers of elements and nodes were given as an average value for all four cases, due to the close number in each case scenario. For high-quality results, the element size was improved for the screw region. The mesh size for the screw region was defined as 0.5 mm, as the contact occurred in the screw region.

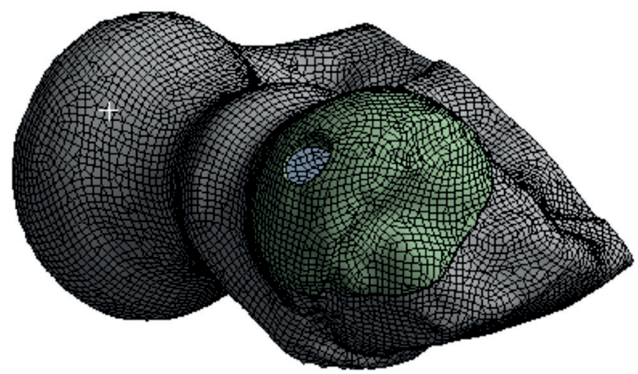

Figure 2. The mesh structure of the finite element analysis

Boundary conditions

A fixed support was applied 1 cm above the superior aspect to the capitellum, according to Saint Venant's continuum mechanics principle. The 1-1.5 Nm preload was applied to the cannulated screws, as the surgeon's insertion torque during the surgical procedure. The FEA models applied a force between 50 N and 300 N (i.e., the force was applied to the capitellum along the arc of the elbow joint, from 0 to 145 degrees in 10° increments). Finally, the IFD results were obtained using ANSYS Workbench software. Frictional contact interactions were assumed between the different parts of the models. The threaded surfaces of the screws were considered as the tie constraints (bone bonded to the screw). The interfaces between the bone and the headless cannulated screw body were simulated by contact pairs, with a friction factor of 0.3 (14). Friction coefficients for bone-bone interaction were 0.46 (15). The boundary conditions of FEA, the fixed support, are shown in Figure 3.

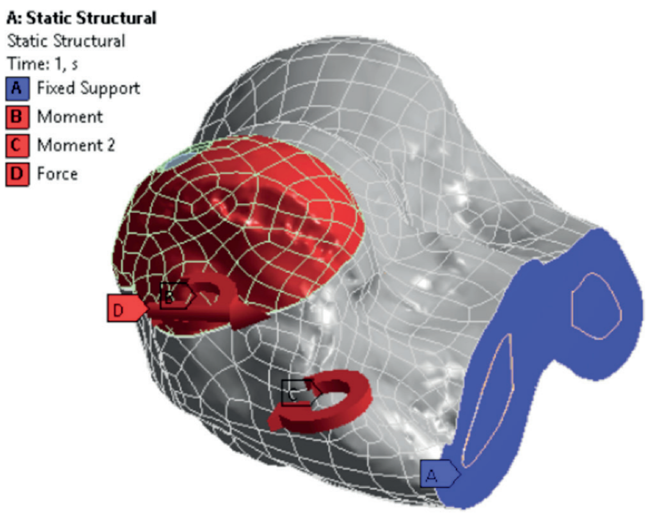

Figure 3. Boundary conditions, fixed support of the finite element analysis

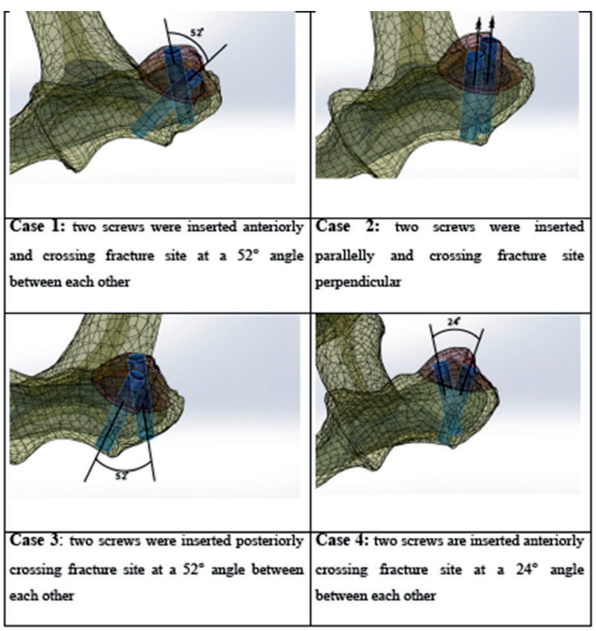

Figure 4. Insertion of randomly pre-determined screw directions

FEA

Four different cases were illustrated with explanations of one pair of headless cannulated screws with different fixation inclinations for type 1 capitellum fracture: (i) Case 1 indicates two screws inserted anteriorly and crossing fracture site at a 52° angle between each other; (ii) Case 2 indicates two screws inserted parallelly and crossing fracture site perpendicular; (iii) Case 3 indicates two screws inserted posteriorly crossing fracture site at a 52° angle between each other; and Case 4 indicates two screws inserted anteriorly crossing fracture site at a 24° angle between each other (Figure 4). The nephrograms of IFD of fracture fixation of the four cases were listed in the ANSYS Workbench software. The X/Y/Z/SUM-component displacements of 16 nodes on the articular surface fracture were determined, and the relative IFD of the fracture was calculated.

Statistical analysis

The Johnson transformation was applied to non-normal displacement data to obtain a set of normally distributed data to carry out a robust statistical analysis. The probability plot of original data was right-skewed and did not seem to be normally distributed, whereas the probability plot of the transformed data was more normally distributed based on the Johnson transformation.

A general linear model was established with the transformed data to investigate the relationship between the factors of screwing inclinations and the force on IFD. According to the model, the displacement in the four cases examined under four different forces presented a significant difference for the “Force” and “Case” factors independently. The analysis did not show an interaction effect of the “Force” and “Case.”

All calculations for displacement and von Mises stress were performed using the Minitab version 17.0 (Minitab Inc., State College, PA, USA) statistical software. A p value of <0.05 was considered statistically significant.

RESULTS

The curative effects of the four different models were compared, and an elaborated analysis of both ‘Force’ and ‘Case’ main effects and ‘Force*Case’ interaction effects in all combinations were conducted. Analysis of displacement (Table 2) exhibited a significant difference in the force values of ‘100N/200N/300N’ and in the screw inclinations of ‘Case 2’ only. Although the interaction effect between Force*Case was observed to be low, the most noticeable results were obtained from the “300N*Case 2.” pair compared to the others (p<0.05) (Figure 5).

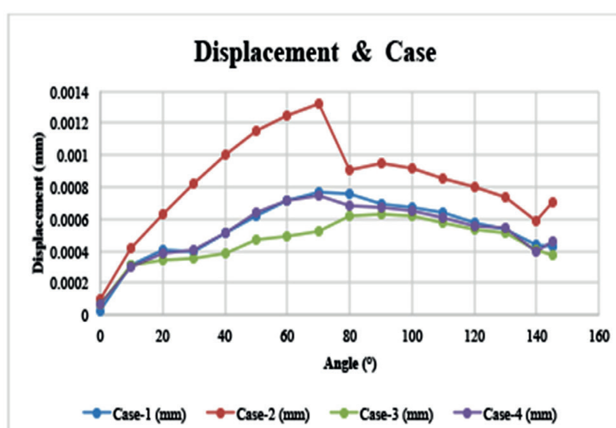

Figure 5. Interfragmentary displacement versus case graph

Table 2. Interfragmentary displacement results chart

Interfragmentary Displacement Results (50N)					Interfragmentary Displacement Results (100N)				
Angle	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)	Angle	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
0	0.00002	0.00009	0.00006	0.00006	0	0.00005	0.00019	0.00013	0.00012
10	0.00031	0.00042	0.00030	0.00029	10	0.00062	0.00084	0.00061	0.00059
20	0.00040	0.00063	0.00033	0.00038	20	0.00081	0.00126	0.00067	0.00076
30	0.00039	0.00082	0.00035	0.00040	30	0.00079	0.00164	0.00071	0.00081
40	0.00051	0.00100	0.00038	0.00050	40	0.00102	0.00201	0.00077	0.00101
50	0.00061	0.00115	0.00047	0.00064	50	0.00122	0.00230	0.00094	0.00128
60	0.00071	0.00125	0.00049	0.00071	60	0.00143	0.00250	0.00098	0.00142
70	0.00077	0.00132	0.00052	0.00074	70	0.00154	0.00264	0.00105	0.00149
80	0.00075	0.00090	0.00062	0.00068	80	0.00151	0.00180	0.00124	0.00136
90	0.00069	0.00094	0.00063	0.00067	90	0.00138	0.00189	0.00126	0.00135
100	0.00067	0.00091	0.00062	0.00065	100	0.00135	0.00183	0.00124	0.00130
110	0.00063	0.00085	0.00057	0.00060	110	0.00126	0.00170	0.00114	0.00121
120	0.00057	0.00079	0.00053	0.00055	120	0.00114	0.00159	0.00107	0.00110
130	0.00053	0.00073	0.00050	0.00053	130	0.00106	0.00146	0.00101	0.00107
140	0.00043	0.00058	0.00040	0.00039	140	0.00086	0.00116	0.00081	0.00078
145	0.00042	0.00070	0.00037	0.00045	145	0.00085	0.00141	0.00074	0.00091
Interfragmentary Displacement Results (200N)					Interfragmentary Displacement Results (300N)				
Angle	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)	Angle	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
0	0.00010	0.00038	0.00026	0.00024	0	0.00016	0.00057	0.00039	0.00036
10	0.00125	0.00168	0.00123	0.00119	10	0.00188	0.00252	0.00184	0.00178
20	0.00163	0.00253	0.00134	0.00153	20	0.00244	0.00379	0.00202	0.00230
30	0.00158	0.00328	0.00142	0.00163	30	0.00237	0.00493	0.00214	0.00244
40	0.00204	0.00402	0.00154	0.00202	40	0.00306	0.00603	0.00231	0.00304
50	0.00245	0.00461	0.00189	0.00256	50	0.00368	0.00691	0.00284	0.00385
60	0.00286	0.00500	0.00197	0.00284	60	0.00430	0.00750	0.00296	0.00426
70	0.00308	0.00529	0.00210	0.00298	70	0.00462	0.00794	0.00316	0.00447
80	0.00303	0.00361	0.00249	0.00272	80	0.00455	0.00542	0.00373	0.00408
90	0.00276	0.00378	0.00253	0.00270	90	0.00414	0.00568	0.00380	0.00405
100	0.00270	0.00367	0.00248	0.00261	100	0.00405	0.00551	0.00372	0.00392
110	0.00253	0.00340	0.00229	0.00243	110	0.00380	0.00511	0.00344	0.00364
120	0.00229	0.00318	0.00214	0.00221	120	0.00344	0.00478	0.00321	0.00331
130	0.00212	0.00293	0.00203	0.00215	130	0.00319	0.00440	0.00304	0.00323
140	0.00173	0.00233	0.00163	0.00157	140	0.00260	0.00350	0.00244	0.00236
145	0.00170	0.00282	0.00148	0.00183	145	0.00255	0.00423	0.00222	0.00275

DISCUSSION

Post-traumatic osteoarthritis (PTOA) following joint trauma may occur at a rate as high as 20 to 74%, and articular fractures increase the osteoarthritis risk by more than 20 folds (16,17). Currently, there is no consensus regarding acceptable intra-articular progression or maximum-tolerable non-anatomical reduction for tibial, acetabular, and wrist fractures in the literature (18-20). In addition, there is a limited number of data regarding PTOA of capitellum. A displaced capitellum fracture requires surgical treatment, and the primary goal of surgical treatment is to obtain a congruent and stable fixation. In an experimental biomechanical study, Elkowitz et al. (21) compared Acutrak™ (Acumed , Hillsbro, OR, USA) and 4.0 mm cancellous lag screws according to their direction. The authors concluded that the Acutrak™ screw provided a more stable fixation independent of whether it was in a posteroanterior (PA) or anteroposterior (AP) direction. In another study, the aforementioned authors compared the Herbert screws and Acutrak™ screws, which were inserted in an AP direction. The Acutrak™ provided a more stable construct than Herbert screws (22). In a case where a stable fixation is not achieved, it may cause joint stiffness (23), pain, non-congruent joint surface malunion and nonunion (24-26). In the literature, there is no study showing the effects of screw inclination on a fracture fixation for capitellar fractures. In the present study, we evaluated the mechanical outcomes of different fixation inclinations formed by headless cannulated screws in the treatment of type 1 capitellum fracture and compared IFD using the FEA. Our study results demonstrated that the angled screw configuration achieved superior stability compared to the parallel ones. The parallel screw configuration may tend to cause early IFD under high magnitude forces. In our study, under axial loading, the angled screw pairs underwent a lower displacement (Figure 5 and Table 2). This can be attributed to the fact that the angled screws provide a better anchorage than the parallel ones, thereby, forming a more stable construct. Increased stability may also improve elbow motion by allowing earlier mobilization and a decline in joint stiffness and related pain.

Nonetheless, there are some limitations to this study regarding both the specimens used and experiment implemented. First, a single specimen was used for this study. However, the size and shape of a humerus can vary considerably among individuals. Therefore, these results may differ for various elbow geometries. On the other hand, the aim of the study was not to provide highly accurate quantities, but rather to compare different fixation inclinations of screws, considering the given anatomy. In this respect, the main conclusion is still valid. Second, no experimental validation was able to be conducted, which is a major limitation. Nevertheless, we examined trends rather than the absolute values. In this respect, the lack of experimental validation is justified. In the future, more realistic biomechanical tests and clinical trials are needed to be conducted to overcome the limitations of our study. Despite these limitations, to the best of our knowledge, this is the first FEA study to compare different fixation inclinations and their effects on a displaced type 1 capitellar fracture.

CONCLUSION

In conclusion, open reduction and internal fixation are standard treatments for displaced capitellum type 1 fractures. The primary goal of treatment is to achieve a stable and congruent fixation, followed by an early mobilization of the elbow joint to prevent stiffness. In our study, the mechanical behaviors of four different screw inclinations to stabilize a displaced type 1 capitellar fracture using FEA were evaluated and superior results were achieved using an angled configuration, compared to the parallel ones. Nonetheless, the results of this study need to be further confirmed by biomechanical tests and clinical trials, as they may provide useful results in the management of displaced capitellum type 1 fractures.

Competing interests: The authors declare that they have no competing interest.

Financial Disclosure: There are no financial supports.

Ethical approval: Since our study is a finite element analysis study, it does not require ethical committee approval.

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