Enhanced Stability of Kirschner Wire Fixation for Articular Fractures of Distal Humerus with Locked Kirschner Wire Fixation: A Finite Element Analysis

Nattapon Chantarapanich, PhD[1], Surasak Jitprapaikulsarn, MD[2], Chantas Mahaisavariya, MD[3]

[1]Department of Mechanical Engineering, Faculty of Engineering at Sriracha, Kasetsart University, Sriracha Campus, Chon Buri, Thailand
[2]Department of Orthopedic, Buddhachinraj Hospital, Phitsanulok, Thailand
[3]Golden Jubilee Medical Center, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

Purpose: *Condylar fractures of distal humerus with or without comminution are difficult to restore and stabilize. Some fracture configurations may not be firmly stabilized by standard plate fixation only. Such conditions, K-wire fixation may be helpful for supplement fixation to fix the articular fragment beyond the area of the plate and screw that can be covered. However, using traditional straight K-wire fixation has been reported with poor outcome. The aim of this study is to evaluate the biomechanical behavior of "locked K-wire fixation" mode – the extraosseous part of K-wire is bended and the bent portion is fixed underneath a small plate and screw – compare with traditional straight K-wire for fixation of condylar fractures of distal humerus.*

Methods: *The 3D model of unicondylar and bicondylar fractures of distal humerus was simulated with type 13-B1, 13-B2 and combined 13-B1+ 13-B2 AO classification intra-condylar fracture based on computed tomography (CT) data. The fixation configuration was created into locked K-wire fixation mode. The stability of fixation method and the von Mises stress were analyzed using finite element analysis (FEA) compared with traditional straight K-wire fixation model. Four loading situation simulated in this study, which were 250 N axial force, 10 N.m bending torsion around frontal, 10 N.m valgus torsion around sagittal axis and 7.5 N.m internal rotation torsion around the longitude axis.*

Result: *Locked K-wire fixation mode provides better stability and lower von Mises stress than straight K-wire fixation in unicondylar fractures in both 13-B1 and 13-B2 AO fracture types. For bicondylar fractures (13-B1+13-B2), locked K-wire fixation using 2-K-wire with bent portion at lateral side provide better stability and lower von Mises stress of K-wire than traditional 2 straight K-wires fixation in almost all loading test. Locked K-wire using 2 K-wire and bent portion at medial side provide better outcome in only axial compression and valgus rotation tests. Using combine 2 locked K-wire with bent portion at medial side and another 2 at lateral side provide better stability and lower von Mises stress than 4 straight K-wire fixation in all testing conditions.*

Conclusion: *Locked K-wire fixation provide better stability than traditional straight K-wire fixation for condylar fracture both for unilateral and bilateral condylar fractures of distal humerus. The method will be benefit in case that the articular fragment cannot be covered by the plate fixation system that need supplement K-wire fixation for unstable condylar fragments.*

Keywords: *Locked K-wire, Distal humerus, fracture, K-wire, Pin and plate*

The Thai Journal of Orthopaedic Surgery: 44 No.1-2: 17-26
Received: *March 12, 2020* ***Revised:*** *March 25, 2020* ***Accepted:*** *April 9, 2020*
Full text. e journal: *http://www.rcost.or.th, http://thailand.digitaljournals.org/index.php/JRCOST*

Introduction

Complex distal humerus fracture is one of the challenging problems in elbow fracture. Articular fracture either from unicondylar or bicondylar with or without comminutions are difficult to obtain anatomical reduction, furthermore, limited the fixation choice[1,2]. The distal humerus is triangular shape with two main columns of medial and lateral parts, connecting the articular portion to the diaphysis. Not only restoration and stable fixation of both columns is crucial, but also restoration and stable fixation of articular portion is necessary[3,4]. Due to comminution of fracture site – either in high energy trauma or osteoporotic fracture – the articular fragment in some cases is not amendable for anatomical locking plate fixation due to the mismatch of location of the fracture fragment and the locking screw[5]. In this situation, Kirschner wire (K-wire) fixation still has the room to fix the

Correspondence to: Mahaisavariya C. Department of Orthopedic Surgery, Golden Jubilee Medical Center, Faculty of Medicine Siriraj Hospital, Mahidol University, Nakhon Pathom, Thailand
E-mail: c.mahaisavariya@gmail.com

fragment and hold the reduction, which facilitate the articular restoration. However, using traditional K-wire fixation has been reported with poor outcome from insufficient stability for early rehabilitation[4]. Currently, Kamrani et al[6] report an interesting modification of K-wire fixation that can enhance the effectiveness of fixation of articular fragment of distal humerus. The modification is that, instead of cutting the protruded portion of K-wires being used to fix the comminuted articular fragment, the K-wires are bended and the bent portion of K-wires are stabilized beneath a small plate fixation to the diaphysis. The method has been reported as "pin and plate fixation" method (Fig. 1). This construction has transformed the conventional straight K-wire fixation into "locked K-wire fixation" mode. This construction mode can fix the articular fragment and limit both translation and rotation of fracture site. Although this method has been reported to be successful in clinical cases[6], there is no scientific investigation of the biomechanical behavior of the method. We, therefore, conduct this study to evaluate the biomechanical behavior, using finite element analysis, of "locked K-wire fixation" mode compare with traditional straight K-wire construction for fixation of articular fracture both in unicondylar and bicondylar fractures of distal humerus.

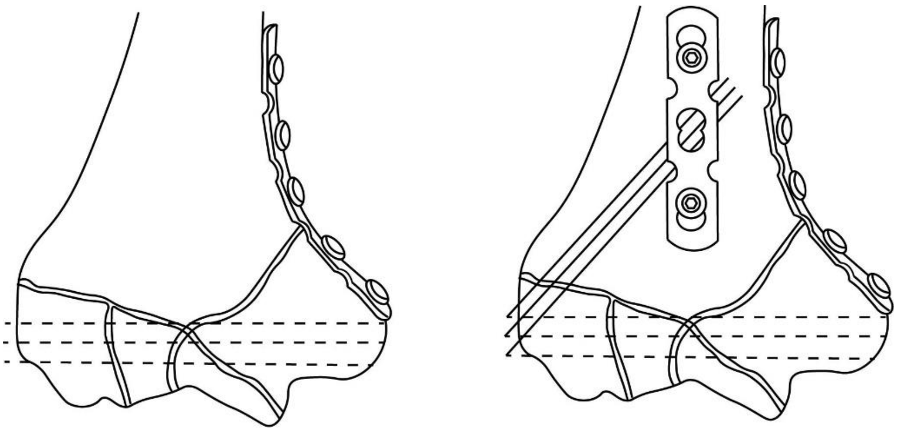

Fig. 1 Traditional use of K-wire fixation (left) and "locked K-wire fixation" mode (right) or "pin and plate fixation" described by Karamni et al.[6]

Materials and Methods

3D Model for Analysis

A computational model of distal humerus was constructed based on computed tomography (CT) data of a male volunteer who has no history of trauma. The CT images was scanned using a spiral CT scanner with slice thickness of 0.625 mm. Each slice image was thresholded to segment pixel containing Hounsfield Unit (HU) in bone density range from the others. Boundary lines were then created to indicate the shape of selected pixels. The set of these lines were used to created 3D models of distal humerus.

The fracture classification under consideration were type 13-B1 and 13-B2 AO classification. The 3D model of distal humerus was simulated intra-condylar fracture by segmenting with inclined lines. Fragment for 13-B1 is 50-mm proximal to joint surface and 20-mm medial to lateral epicondyle whereas fragment for 13-B2 is 50-mm proximal to joint surface and 20-mm lateral to medial epicondyle. There are nine cases included in this study which fractures were fixed with K-wire in different surgical techniques, described as follows:

(1) 13-B1 fracture fixed with 2 straight K-wires,
(2) 13-B2 fracture fixed with 2 straight K-wires,
(3) 13-B1 combined with 13-B2 fractures fixed with 2 straight K-wires,
(4) 13-B1 fracture fixed with 2 bent K-wires,
(5) 13-B2 fracture fixed with 2 bent K-wires,
(6) 13-B1 combined with 13-B2 fractures fixed with 2 bent K-wires in medial side,
(7) 13-B1 combined with 13-B2 fractures fixed with 2 bent K-wires in lateral side,
(8) 13-B1 combined with 13-B2 fractures fixed with 4 straight K-wires, and
(9) 13-B1 combined with 13-B2 fractures fixed with 4 bent K-wires. (2 bent K-wires in medial side and 2 bent K-wires in lateral side)

After each 3D models for each case were created, they were exported to parasolid file format for finite element (FE) model development (Fig. 2).

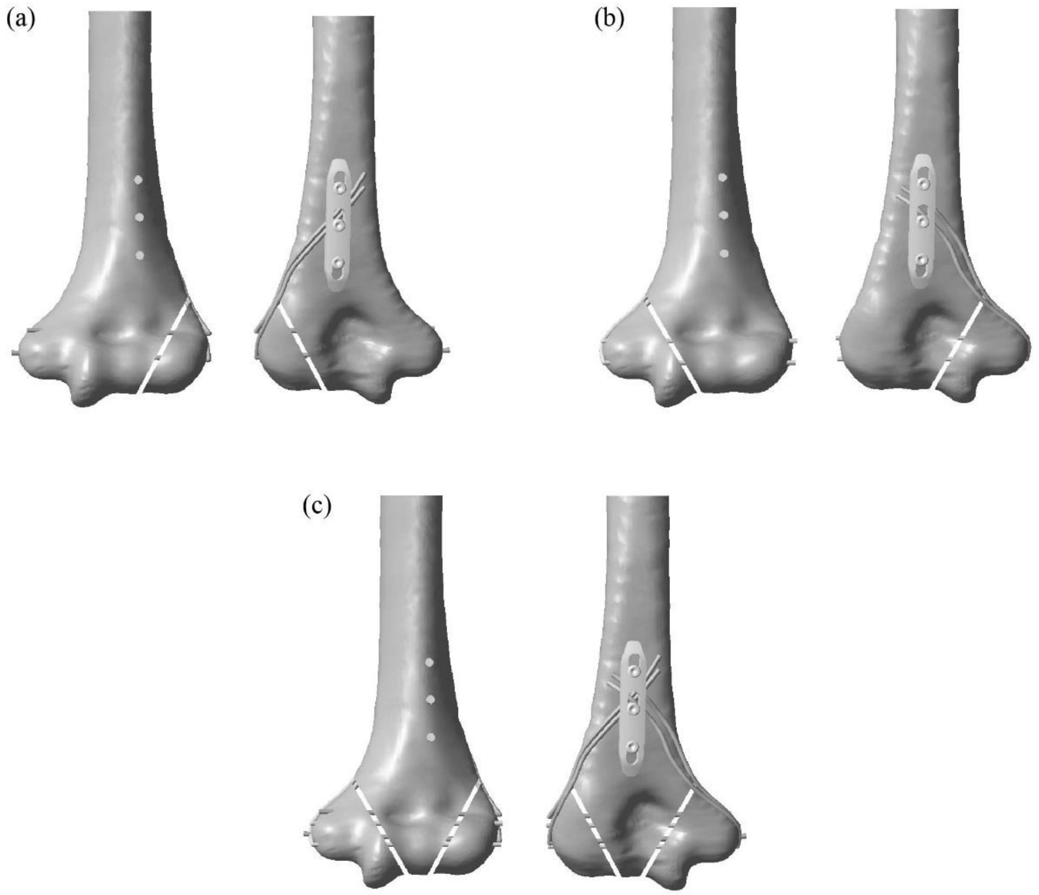

Fig. 2 (a) 3D model of 13-B1 fixed with 2 bent K-wires.
(b) 3D model of 13-B2 fixed with 2 bent K-wires.
(c) 3D model of 13-B1 combined with 13-B2 fractures fixed with 4 bent K-wires.

Finite Element Model

The 3D models in parasolid file format were transformed to node and element for FE analysis. Element type used in the analysis was 4-node tetrahedral element (MSC Patran/Marc Mentat). The number of nodes and elements employed in the analysis depends on element convergence test. It carried out to obtain the minimum number of nodes and elements that ensures the FE results are not affected by changing the number of elements.

In order to perform convergence test, one of the FE model case, 13-B2 fracture fixed with 2 straight K-wires, assigned with material properties and loading condition as explained in later sections, was generated with four different number of elements. Stress exhibited in K-wire and fracture displacement was set as observed parameters. The number of elements which was equal or greater the least number of elements that do not significantly change in K-wire stress and fracture displacement results would be used for FE analysis.

Material properties assigned to FE models were assumed to be homogenous and isotropic linearly elastic. K-wires were designated properties as stainless steel whereas bone regions were designated properties according to Mendoza-Muñoz et al.[7] Elastic modulus and Poisson's ratio of cortical bone and cancellous bone are 14,200 MPa with Poisson's ratio 0.30, and 300 MPa with Poisson's ratio 0.12, respectively. For K-wire, as made from stainless steel, elastic modulus is 200,000 and Poisson's ratio is 0.30[8].

Loading and Boundary Conditions

Loads were acted to distal humerus at the interaction points on the articular surface of trochlea. There are four loading situations simulated in this study, which were 250 N axial force along the longitude axis pointing proximal direction to imitate the compression force, 10 N.m bending torsion around frontal axis to imitate the distal humerus being bent backward, 10 N.m valgus torsion around sagittal axis to imitate the distal humerus being bent laterally, and 7.5 N.m internal rotation torsion around the longitude axis to imitate the distal humerus twisting[8]. Constrains in every degree of freedoms were applied at proximal end of the humeral shaft.

In clinics, for the case which K-wires were bent, fixed and compressed with plate and screw system, the other end of K- wires were fully constrained to mimic the compression effect.

Cancellous and cortical bone regions were defined as no relative displacement to each other. K-wires fixed into the bone were also assumed to be osseointegration, not relative displacement to bone. The bent portions of K- wire were given relative displacement conditions as they can move freely on the bone surface (Fig. 3).

The study protocol was reviewed and approved by the IRB of the authors' affiliated institutions.

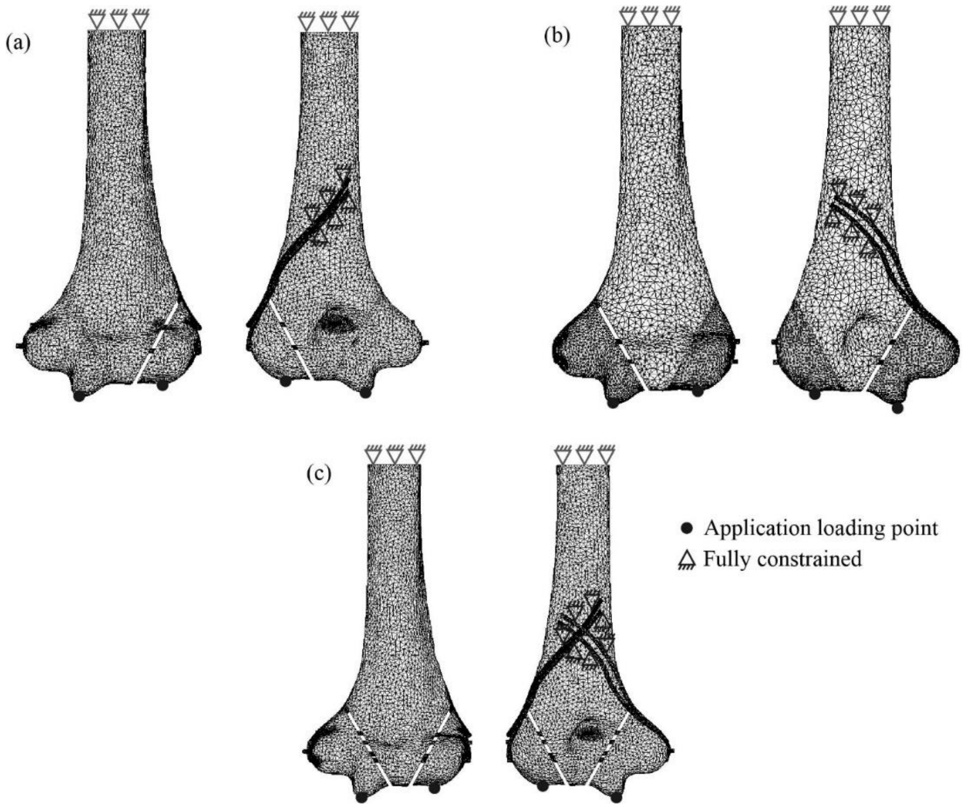

Fig. 3 (a) FE model of 13-B1 fixed with 2 bent K-wires.
(b) FE model of 13-B2 fixed with 2 bent K-wires.
(c) FE model of 13-B1 combined with 13-B2 fractures fixed with 4 bent K-wires.

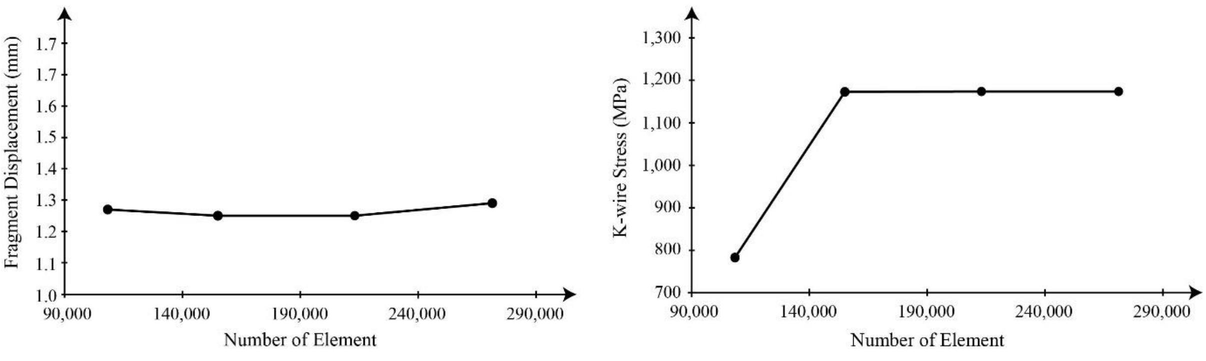

Fig. 4 The results of convergence test, the number of elements and corresponding nodes would be employed with no less than this number.

Results

Convergence Test

The results of convergence test are shown in Figure 4. The number of element equal or greater than 154,999 elements with 37,565 nodes presents no significant change in both K- wire stress and fracture displacements. Therefore, in all FE analysis models, the number of elements and corresponding nodes would be employed with no less than this number.

Fracture displacement and K-wire stress

Fragment displacement and K- wire stress occuring in different loading conditions are shown in Tables 1-4.

A) Unicondylar fracture (13-B1, 13-B2)

Locked K-wire fixation using 2 K-wires provides better stability at fracture site (lesser fracture displacement) than fixation with conventional 2 straight K-wires in all testing conditions. The similar results occur in either lateral (13-B1) and medial condylar fracture (13-B2). The von Mises stress of the K-wire at fracture site using 2 locked K-wires fixation method is lower than 2 straight K-wires fixation in almost all testing conditions. Only lateral condylar fracture (13-B1) with 2 locked K-wires fixation has substantially greater von Mises stress than 2 straight K-wires fixation.

B) Bicondylar fractures (13-B1+13-B2)

- Locked K-wire fixation using 2 K-wires with bent portion at lateral side, provides better stability at fracture site (lesser fragment displacement and lesser von Mises stress of K-wires) than fixation with conventional 2 straight K-wires in all testing conditions.

- Locked K-wire fixation using 2 K-wires with bent portion at medial side, provides better stability than 2 straight K-wires fixation (lesser fragment displacement) in only axial loading and valgus torsion tests. But the stability is weaker in bending torsion and rotation torsion loads. The von Mises stress of K-wires at fracture surface is lower than 2 straight K-wire fixation in almost all testing conditions except valgus torsion loading.

- Fixation using 4 straight K-wires provides better stability than fixation with 2 straight K-wires in all testing conditions. The von Mises stress of K-wires at fracture site using 4 straight K-wires is also lower than using 2 straight K-wires in almost all testing condition except axial compression test.

- Locked K-wire fixations with 2 K-wires bent portion at lateral side combine with another 2 K-wires with bent portion at medial side, provide better stability than using only 2 locked K-wire fixations, either the bent portion at medial or lateral side. The stability is also better than using 4 straight K-wires fixation. The von Mises stress of K-wires is also lowest when compare to other studied fixation methods.

Table 1 Fracture displacement and K-wire stress under axial compression.

Fracture case	Fixation	Fragment Displacement (mm)		K-wire stress (MPa)
		Medial Condyle	Lateral Condyle	
13-B1	2 straight K-wires	-	1.18	783.65
13-B2	2 straight K-wires	1.25	-	1173.21
13-B1 combined with 13-B2	2 straight K-wires	4.57	3.15	1608.73
13-B1	2 bent K-wires	-	0.91	542.04
13-B2	2 bent K-wires	0.99	-	473.29
13-B1 combined with 13-B2	2 bent K-wires medial side	1.17	0.68	1099.41
13-B1 combined with 13-B2	2 bent K-wires lateral side	2.22	1.09	811.61
13-B1 combined with 13-B2	4 straight K-wires	1.05	0.56	3109.28
13-B1 combined with 13-B2	4 bent K-wires	0.83	0.45	476.14

Table 2 Fracture displacement and K-wire stress under bending torsion.

Fracture case	Fixation	Fragment Displacement (mm)		K-wire stress (MPa)
		Medial Condyle	Lateral Condyle	
13-B1	2 straight K-wires	-	1.47	543.21
13-B2	2 straight K-wires	2.15	-	1055.87
13-B1 combined with 13-B2	2 straight K-wires	1.79	1.96	5071.94
13-B1	2 bent K-wires	-	0.87	846.93
13-B2	2 bent K-wires	1.14	-	288.21
13-B1 combined with 13-B2	2 bent K-wires medial side	2.25	2.97	736.40
13-B1 combined with 13-B2	2 bent K-wres lateral side	1.57	1.03	802.48
13-B1 combined with 13-B2	4 straight K-wires	1.08	0.81	1635.52
13-B1 combined with 13-B2	4 bent K-wires	0.64	0.43	262.40

Table 3 Fracture displacement and K-wire stress under valgus torsion.

Fracture case	Fixation	Fragment Displacement (mm)		K-wire stress (MPa)
		Medial Condyle	Lateral Condyle	
13-B1	2 straight K-wires	-	0.56	288.14
13-B2	2 straight K-wires	0.52	-	148.38
13-B1 combined with 13-B2	2 straight K-wires	1.21	0.96	2058.50
13-B1	2 bent K-wires	-	0.48	163.07
13-B2	2 bent K-wires	0.46	-	131.34
13-B1 combined with 13-B2	2 bent K-wires medial side	0.91	0.90	2828.50
13-B1 combined with 13-B2	2 bent K-wires lateral side	1.14	0.59	461.66
13-B1 combined with 13-B2	4 straight K-wires	0.66	0.58	1386.06
13-B1 combined with 13-B2	4 bent K-wires	0.55	0.53	177.65

Table 4 Fracture displacement and K-wire stress under rotational torsion.

Fracture case	Fixation	Fragment Displacement (mm)		K-wire stress (MPa)
		Medial Condyle	Lateral Condyle	
13-B1	2 straight K-wires	-	2.76	1681.91
13-B2	2 straight K-wires	4.23	-	6070.95
13-B1 combined with 13-B2	2 straight K-wires	3.09	2.26	4997.10
13-B1	2 bent K-wires	-	0.90	1544.01
13-B2	2 bent K-wires	2.30	-	4776.57
13-B1 combined with 13-B2	2 bent K-wires medial side	0.81	5.50	2748.99
13-B1 combined with 13-B2	2 bent K-wires lateral side	0.84	1.77	1053.44
13-B1 combined with 13-B2	4 straight K-wires	1.60	0.93	1259.22
13-B1 combined with 13-B2	4 bent K-wires	1.20	0.63	1084.02

Discussion

The goals of treatment for fractures of distal humerus are to restore articular surface and to stabilize the fragments adequately enough for early range of elbow motion(9,10). In cases with varying degrees of comminution in both the medial and lateral columns, rigid fixation of both columns is necessary for early rehabilitation(10). Currently, fixation methods, either perpendicular or parallel double locking plates, are widely accepted to fix both the medial and lateral columns(11- 15). The articular portion will be stabilized by the locking screw of the plate. However, in some cases, the fractures are comminuted and some fracture fragments may not be included within the plate fixation area. In such condition, multiple small K-wire fixations will be useful for adjuvant fixation. Traditionally, the portion of K- wires outside the bone was normally bended and cut at few millimeters beyond the surface boundary of the bone. This is to ease K-wire removal if needed in later stage. According to Kamrani's method(6), the K-wires are bended and the bent portion of the K-wires are fixed with small profile plate to the diaphysis. This construction has transformed the straight K-wire fixation mode into "locked K-wire fixation" mode.

From our study, locked K-wire fixation provides better stability of fixed articular fragment, with lower von Mises stress of the K-wire at the fracture site than straight K-wire fixation in almost all loading conditions of unicondylar fracture. This may be that fixation using locked K-wire, the 2 ends of the K-wire have been firmly stabilized instead of one end of the straight K-wire fixation. This will help lessen the degree of freedom of the motion of fixed fracture fragment.

For bicondylar fractures, 2 locked K-wire fixations with bent portion at lateral side provide better stability with lower stress of K-wire at fracture than fixation with 2 straight K-wires. Fixation using 2 locked K-wires fixations with bent portion at medial aspect provide superior stability than 2 straight K-wires fixations only axial compression and valgus torsion load. The method is inferior in bending torsion and rotation torsion. The findings show that the construction with bent portion at lateral aspect will provide more advantages and more versatility than the construction with the bent portion at the medial aspect. The authors believe that these results may relate to the anatomical bony configuration and the loading test.

Increasing the number of straight K-wire fixations for bicondylar fractures will provide better stability than using 2 straight K-wires fixations. However, the von Mises stress is found to be higher. This may be that when the 4 K-wires were holding the construction, most of the stress go to the K-wires to keep stability of the whole set of fracture fragments with smaller relative motion between fracture fragments.

Fixation of bicondylar fractures (13-B1+ 13-B2) by 2 locked K-wires with bent portion at lateral and 2 locked K-wires with bent portion at medial side have shown to provide better stability and lower von Mises stress than other constructions in this study. The authors believe that this construction, the locked K-wire fixation mode, provides more stability of each condylar fragment by firm fixation of the K-wire to the intact bone of distal humerus and at the area beneath the plate. The bearing stress can distribute to the K-wire and the intact bony part result in lower von Mises stress of the K-wire at fracture sites.

Strength and Weakness of the Study

This study is intended to evaluate the advantages of "locked K-wire fixation" mode over the conventional straight K-wire fixation. The finite element analysis (FEA) is a well accepted method in such a kind of evaluation. The fracture patterns for the study include unilateral condylar fracture type 13-B1 and 13-B2 and bicondylar fractures (combined 13-B1 and 13-B2). The authors used only 2 K-wires for the study of unicondylar fracture. This is because we intended to verify the biomechanical behavior of "locked K-wire fixation" mode and compare to that of the "conventional straight K-wire fixation". Using two K-wires for fixation will be smallest number for the comparison of the mechanical effect. Too many K-wires for the studied models will not be practical in clinical setting and their substantially different effects may not be identified. Construction with single K-wire is not appropriate for comparison because the result may be influenced by rotation of the fracture fragment around the single K-wire during loading test and will be more difficult for the interpretation. However, the authors did not use the comminuted fracture model (AO 13C type fracture) for the study because of the technical difficulty of the evaluation by FEA from multiple fragmented bones. We did not perform any comparison of the "locked K-wire fixation" to any standard locking plate fixation because the construction of fixation in this study cannot replace the standard fixation of complex distal humeral fracture by locking plate. The method will benefit in case that the articular fragment is beyond the plate fixation and needs supplement fixation by K-wire, choosing "locked K-wire fixation" mode instead of straight K-wire fixation to benefit for better stability of articular fragment and reduce the risk of K-wire breakage.

We use the term "locked K-wire fixation" instead of "pin and plate fixation" that has been firstly described to fix complex distal humeral fractures by Kamrani et al(6) and later applied for the treatment of supracondylar nonunion of humerus(16). This is because this technical concept is to enhance

K-wire fixation by conversion of conventional straight K-wire fixation which usually will have one free end into the bent K-wire configuration, firmly fixed at both ends. The first report of this technique describes the use of an extra plate to fix the proximal end of the bent portion of K-wires. On the other hand, to achieve this principle the bent portion of the K-wire can be stabilized beneath the adjacent plate that is already being used for fixation of the medial or lateral column fractures of the distal humerus. It can also be stabilized by using other means such as washer and screw or locking to a screw head fixation at the intact bone proximal to the fracture area.

Clinical Relevance

Fixation of complex fractures of distal humerus requires anatomical reduction and stable fixation to resume early range of motion rehabilitation program postoperatively. In some case that the plate system can be applied effectively in only one column, and the fracture pattern has been turned from AO 13-C to either 13-B1 or 13-B2, the locked K-wire fixation can be applied for adjuvant fixation instead of straight K-wire fixation to fix the unstable unicondylar fragment.

If both columns cannot be perfectly restored due to the low fracture lines of the articular fragments, both condyles are located beyond the plate fixation, this locked K-wire fixation may be helpful. If only 2 or 3 K-wires can be used, the bent portion should be placed at lateral side. If more K-wires can be applied for the stability of both condyles, the bent portion should be applied to both sides for more stability of each condylar fragment.

In conclusion, the method of bent K-wire combined with plate fixation or "locked K-wire fixation" provides better stability than traditional straight K-wire fixation for articular fragment of distal humerus, either unicondylar or bicondylar fractures. The small K-wire is easily available, easy to use, more freedom of direction to fix and less problems with iatrogenic bursting of bone fragment. Increase numbers of K-wire fixation can also increase more stability of the construction. With stable fixation construction, early range of motion is allowed and can help both restoration of articular surface and prevent the stiffness of mobile joints. The bent portion of the K-wires may be stabilized beneath the plate intending to be used to fix the nearby associated metaphyseal fracture with no need to use an extra-plate as described.

Conflict of interest declaration

All authors declare no personal or professional conflicts of interest, and no financial support from the companies that produce and/or distribute the drugs, devices, or materials described in this report.

Acknowledgement

The authors would like to thank Professor Banchong Mahaisavariya for his expert advice and encouragement throughout this difficult study.

References

1. John H, Rosso R, Neff U, Bodoky A, Regazzoni P, Harder F. Operative treatment of distal humeral fractures in the elderly. J Bone Joint Surg Br. 1994; 76(5): 793-6.
2. Jost B, Adams RA, Morrey BF. Management of acute distal humeral fractures in patients with rheumatoid arthritis. A case series. J Bone Joint Surg Am. 2008; 90(10): 2197-205.
3. Jung SW, Kang SH, Jeong M, Lim HS. Triangular Fixation Technique for Bicolumn Restoration in Treatment of Distal Humerus Intercondylar Fracture. Clin Orthop Surg. 2016; 8(1): 9-18.
4. Nauth A, McKee MD, Ristevski B, Hall J, Schemitsch EH. Distal humeral fractures in adults. J Bone Joint Surg Am. 2011; 93(7): 686-700.
5. Aktan C, Ertan MB, Turan A, Kose O. Fixation of Small Osteochondral Fragments in a Comminuted Distal Humerus Fracture with Magnesium Bioabsorbable Screws: A Case Report. Cureus. 2018; 10(12): e3752.
6. Kamrani RS, Mehrpour SR, Aghamirsalim MR, Sorbi R, Zargar Bashi R, Kaya A. Pin and plate fixation in complex distal humerus fractures: surgical technique and results. Int Orthop. 2012; 36(4): 839-44.
7. Mendoza-Muñoz I, González-Ángeles A, Siqueiros-Hernández M, Montoya-Reyes M. Biomechanical principles used in finite element analysis for proximal humeral fractures with locking plates. Med Sci Tech. 2017; 58: 128-36.
8. Chantarapanich N, Sitthiseripratip K, Mahaisavariya B, Siribodhi P. Biomechanical performance of retrograde nail for supracondylar fractures stabilization. Med Biol Eng Comput. 2016; 54(6): 939-52.
9. Wei L, Ling M, An Z. Biomechanical analysis of a novel plating for intra-articular distal humerus fractures: combined anteromedial and anterolateral plating. J Orthop Surg Res. 2019; 14(1): 132.
10. Yang KH, Park HW, Park SJ, Jung SH. Lateral J-plate fixation in comminuted intercondylar fracture of the humerus. Arch Orthop Trauma Surg. 2003; 123(5): 234-8.
11. Reising K, Hauschild O, Strohm PC, Suedkamp NP. Stabilisation of articular fractures of the distal humerus: early experience with a novel perpendicular plate system. Injury. 2009; 40(6): 611-7.
12. Stoffel K, Cunneen S, Morgan R, Nicholls R, Stachowiak G. Comparative stability of perpendicular versus parallel double-locking

plating systems in osteoporotic comminuted distal humerus fractures. J Orthop Res. 2008; 26(6): 778-84.

13. Penzkofer R, Hungerer S, Wipf F, von Oldenburg G, Augat P. Anatomical plate configuration affects mechanical performance in distal humerus fractures. Clin Biomech (Bristol, Avon). 2010; 25(10): 972-8.
14. Got C, Shuck J, Biercevicz A, Paller D, Mulcahey M, Zimmermann M, Blaine T, Green A. Biomechanical comparison of parallel versus 90- 90 plating of bicolumn distal humerus fractures with intra- articular comminution. J Hand Surg Am. 2012; 37(12): 2512-8.
15. Kudo T, Hara A, Iwase H, Ichihara S, Nagao M, Maruyama Y, Kaneko K. Biomechanical properties of orthogonal plate configuration versus parallel plate configuration using the same locking plate system for intra- articular distal humeral fractures under radial or ulnar column axial load. Injury. 2016; 47(10): 2071-6.
16. Kamrani RS, Oriadi LZ. Treatment of humerus supracondylar nonunion with pin and plate fixation as a simple device. Chirugie de la main 2015; 34(6): 332.

การศึกษาประสิทธิภาพของลวดดามในการเพิ่มความเสถียรของรอยแตกในบริเวณกระดูกต้นแขนส่วนปลายด้วยการจำลองในคอมพิวเตอร์ด้วยวิธีไฟไนต์เอลิเมนต์

ณัฐพล จันทร์พาณิชย์, ปร.ด, สุรศักดิ์ จิตประไพกุลศาล, พบ, ฉันทัส มไหสวริยะ, พบ

วัตถุประสงค์: ภาวะกระดูกหักบริเวณกระดูกต้นแขนส่วนปลายอาจพบอุปสรรคในการยึดตรึงกระดูกเนื่องจากชิ้นหัก อาจอยู่ในตำแหน่งที่ไม่สามารถใช้แผ่นดามและสกรูยึดตรึงได้มั่นคง การใช้ K-wire ช่วยยึดเสริมมีความจำเป็นและมีประโยชน์ในบางกรณี แต่มีความแข็งแรงต่ำและให้ผลการรักษาไม่ดี การศึกษานี้มีจุดประสงค์เพื่อทดสอบความแข็งแรงทางกลศาสตร์ของการตรึงกระดูกบริเวณนี้ด้วยเทคนิคใหม่แบบ locked K-wire fixation เทียบกับเทคนิคทั่วไปแบบดั้งเดิมที่ใช้ straight K-wire fixation

วิธีการศึกษา: ภาพ 3มิติของกระดูกต้นแขนส่วนปลายจะถูกจำลองขึ้นในลักษณะ รอยหักแบบ 13-B1 และ 13-B2 ตามการจำแนกแบบ AO หลังจากจำลองการยึดตรึงกระดูกด้วยเทคนิค locked K-wire fixation แล้วจะถูกนำไปวิเคราะห์ทางชีวกลศาสตร์ด้านคุณภาพในการยึดตรึงรอยหักและ von Mises stress ที่เกิดขึ้นโดยเทียบกับเทคนิคแบบดั้งเดิม (straight K-wire fixation) โดยแรงที่ใช้ทดสอบ ประกอบด้วยแรง 4 ชนิด ได้แก่ axial compression, bending torsion, valgus torsion และ rotation torsion ขนาด 250 นิวตัน, และ 10, 10, และ 7.5 นิวตัน-เมตร ตามลำดับ

ผลการศึกษา: การยึดตรึงกระดูกหักชนิด unicondylar fracture ด้วย locked K-wire fixation โดยใช้ K-wire 2 เส้นให้ความมั่นคงมากกว่าเทคนิคดั้งเดิมที่ยึดด้วย straight K-wire สองเส้น สำหรับรอยหักชนิด bicondylar การใช้ Locked K-wire 2 เส้นโดยส่วนงอของ K-wire อยู่ทางด้านนอกให้ความมั่นคงมากกว่าวิธี straight K-wire 2 เส้นแทบทุกมิติของแรงที่ใช้ทดสอบ เมื่อใช้ locked K-wire 4 เส้นโดย 2 เส้นให้ส่วนงออยู่ทางด้านนอก และอีก 2 เส้นให้ส่วนงออยู่ทางด้านในพบให้ผลการยึดตรึงรอยหักได้ดีกว่าวิธี straight K-wire 4 เส้น และดีกว่า locked K-wire fixation โดยใช้ K-wire เพียง 2 เส้น

สรุป: Locked K-wire fixation ให้ความแข็งแรงในการยึดตรึงกระดูก มากกว่า ตลอดจนเกิดความเค้นที่ K-wire (von Mises stress) ที่ต่ำกว่าเทคนิคดั้งเดิม (straight K-wire fixation) ทั้งรูปแบบรอยหักทีเป็น unilateral และ bilateral condylar เมื่อใช้จำนวน K-wire เท่ากัน