Forty-five-degree or higher insertion angles are required to penetrate the opposite cortex in bicortical applications of Kirschner wires: an in vitro study on sheep bones

Mehmet Colak · Burak Gurer · Mehmet Ali Sungur ·
Metin Manouchehr Eskandari

Received: 8 February 2011 / Accepted: 4 April 2011 / Published online: 7 May 2011
© Springer-Verlag 2011

Abstract

Purpose Slippage of the wires over the opposite cortex from the endosteal side is frequent and can lead to insufficient stability. This in vitro biomechanical study was planned to investigate the angle of wire insertion that leads to trans cortex perforation.

Methods Long bones of sheep were cut longitudinally into two pieces and half bones were stabilised on a frame. Three orthopaedic surgeons performed the experiment using ten wires of four different diameters at two different drilling speeds. Each wire was introduced from the endosteal side at angles starting at 30° in 5° increments until perforation. When perforation was achieved, the angle was recorded. To determinate the critical angle of perforation, receiver operating characteristic (ROC) curve analyses was performed. Two-way factorial analysis of variance (ANOVA) and Kruskal–Wallis tests were used for statistical comparisons.

Results Kirschner-wire insertion angles of $\geq 45^\circ$ provided perforation with a percentage of 83.9 %. Wire diameter, drilling speed and surgeon variables had no effect on perforation angles ($p > 0.05$).

Conclusion If preoperative evaluation of fractures to be fixed by K wires reveals the need for oblique wire insertion angle $< 45^\circ$, a standard trocar-tip K wire application would lead to slippage of the wire tip on the endosteal surface of the opposite cortex. According to this study, the operative plan should be changed if such obliquity of the K wire is mandatory during bicortical applications.

Introduction

Although Kirschner (K) wires are commonly used fixation devices in orthopaedic trauma, all aspects of their biomechanical properties have not yet been described. Paediatric supracondylar humeral fractures, proximal humeral fractures and fractures of distal radius are frequent fields of usage for K wires [1–6]. Fixation of these fractures should provide sufficient stability so that fragment reduction will not be lost before the end of the healing process. The literature provides information on the effects of pin-tip configuration and drilling speed on stability [7, 8]. There is also some information about the effects of tip configuration, drilling speed and driving angle in relation to pin slippage over the periosteal surface of the near cortex.

It has been shown that passing both near and far cortices (bicortical fixation mode) gives better stability than intramedullary fixation by K wires [9]. In clinical practice, we noticed that during bicortical fixation, slippage of the pin tip over the opposite cortex occurs frequently. When accepted, this type of fixation leads to less stability at the fracture site. This feature seems to occur when fracture placement and configuration dictates a low insertion angle between K wire and longitudinal axis of the bone. These are fractures of the metaphyseal–diaphyseal junction of the distal and proximal humerus in children and distal radius in

M. Colak · B. Gurer · M. M. Eskandari
School of Medicine, Department of Orthopaedics and
Traumatology, University of Mersin,
Mersin, Turkey

M. A. Sungur
Department of Biostatistics, University of Mersin,
School of Medicine,
Mersin, Turkey

M. Colak (✉)
Mersin Universitesi Tip Fakultesi Hastanesi,
Zeytinlibahce cad., Necdet Ulger Binasi, 2. kat,
33079, Mersin, Turkiye
e-mail: drmcolak@hotmail.com

adults. The biomechanical study presented here was planned to investigate the relationship between insertion angle and the possibility of passage or slippage over the endosteal surface of the opposite cortex. For this purpose, a standardisation technique was developed, and K wires with four different diameters were tested by three orthopaedic surgeons.

Materials and methods

Selected materials were specially prepared sheep long bones and standard K wires with four different diameters. Long bones of young adult sheep were obtained from a local butcher within six hours of slaughter. Soft tissues were removed. As the question of study focused on endosteal surface perforation, all bones were cut longitudinally into two pieces. Bones with abnormal irregularities on the inner cortex or excessive bowing were excluded from the study. Standard trocar-point stainless steel K wires (Ortopro, Izmir, Türkiye) in four different diameters (1.5, 1.8, 2.0 and 2.2) were used. Characteristic information about K wires including tip design supplied by producer firm is given in Fig. 1.

The selected methodology was based on using a specially designed standardisation frame for application and evaluation of the experiment. The frame was con-

structed using circular external fixation equipment fixed on a heavy marble table (Fig. 2). The frame included a standard circular goniometer to set and evaluate the pins' insertion angles, a wire-aiming unit constructed of two cannulated bolts linked on each side of a rotating plate and a bone fixation unit. For the wire-aiming unit, two different sets of cannulated bolts were used. Standard bolts with 2.0-mm-diameter holes were used for 1.5 and 1.8 mm K wires, and bolts with specially widened holes to 2.3 mm were used for 2.0 and 2.2 mm K wires. The outer bolt was used only for ease of aiming the wires, whereas the closer one also represented the inducement effect of the near cortex. The bone-fixation unit's link to the base frame was designed to be adjustable to ease fine tuning the position of the bone pieces and the region of each bone piece to be tested. Using this feature, the cortex of each half bone longitudinal axis was placed perpendicular to the 90° line of the goniometer. This feature also facilitated insertion of wires on a single untouched region of a bone segment. Each piece of half bone was fixed with two Schanz screws over the fixation unit. For each bone piece, the fixation unit was adjusted over the base frame so that the endosteal surface of the bone was set 3 cm apart from the outlet hole of the closer bolt when the aiming unit was perpendicular to the bone. This distance was set according to the results of pilot radiographic measurements of surgically fixed paediatric humeral supracondylar and adult distal radius fractures (unpublished data). These studies revealed that the perpendicular distance between K-wire entrance point on metaphyses and the longitudinal axis of diaphyseal trans cortex on anteroposterior X-rays were 22–38 mm (mean 33 mm) in humeral supracondylar fractures (Fig. 3) and 22–28 mm (mean 26 mm) in distal radial fractures.

Three orthopaedic surgeons performed the experiment using ten wires of four different diameters and two different drilling speeds. A battery-powered drill (SF 121-A, Hilti, Liechtenstein) with two adjustable drilling speeds (400 rpm with gear 1 and 1,300 rpm with gear 2) was used. Pins were held in the drill so that tips were of equal length from the grasping chuck. This distance was invariably 165 mm. Each pin was introduced at angles starting from 30° (this angle always caused slippage) with 5° increments until perforation (Fig. 4). When perforation was achieved, the angle between bone and wire was recorded. After testing each K-wire group, drilling speed was changed from 400 to 1,300 rpm, and the procedure was repeated on new bone segments. During tests with each drilling speed, the surgeons were asked to use the maximum of the selected speed by sharp triggering of the drill button. Using movable bone fixation units, each K wire was introduced on an untested bone region to eliminate the possible effects of bone irregularity produced by the previously tested K wire.

Fig. 1 Pin-tip design. Trocar point was created by three cuts 120° to each other. The length of the cutting surfaces (X) varies with different diameter wires

Fig. 2 Study frame holding the half bone with fixation unit (arrowhead), goniometer and aiming bolts: top view (a) and front view (b). The closer bolt (arrow) also represented the inducement effect of the cis (near) cortex

Statistical analyses were performed using SPSS 11.5 program (SPSS Inc., USA). To determinate the critical angle of perforation, receiver operating characteristic (ROC) curve analyses were performed and a cutoff value calculated. Effects of wire diameter and drilling speed on perforation angles were tested by two-way factorial analysis of variance (ANOVA). Kruskal–Wallis test was used to calculate intersurgeon variability between perforation angles for each wire diameter and drilling speed. Results were considered significant when *P* values were smaller than 5%.

Results

Results revealed that the minimal critical angle of perforation is 45° and that wire diameter, drilling speed and

surgeon variables have no effect on perforation angles. Median values of perforation angles achieved by all studied wire diameters in two different drilling speeds are given in Table 1. Analysis of these data showed that K-wire insertion angles $\geq 45^\circ$ provided perforation with a percentage of 83.9% [95% confidence interval (CI) 78.6–88.3] ($p=0.001$). Main effects of wire diameter and drilling speed on perforation angles were not statistically significant ($p=0.44$ and 0.411 respectively). Interaction between wire diameter and drilling speed made no significant difference ($p=0.842$). Statistical analyses revealed no difference in perforation angles between three surgeons with each wire diameter and drill speed ($p>0.05$).

Discussion

Stability level of K-wire fixation depends on multiple factors, but among them, engaging the opposite cortex remains the most important. Other factors that induce stability are higher number of wires passing the fracture line, higher angles among the inserted wires where they cross each other, distance of the crossing point of the wires from the fracture line and using wires with threaded tips in the metaphyseal regions [6, 10–13]. In clinical practice, we noticed that obliquity of the fracture line or its distance from the wire entrance point frequently dictates low K-wire insertion angles in relation to the opposite cortex, which might lead to difficulty in perforation of that cortex and consequently to difficulty in obtaining appropriate stability levels. Thus, we designed this study to evaluate the factors that might influence perforation of the opposite cortex by K wires.

Results of the study revealed that insertion angle is the unique factor determining passage of a K wire from the opposite cortex. According to these results, standard trocar-point wires could perforate and pass opposite cortices when inserted at $\geq 45^\circ$. We think this finding is valuable in preoperative planning of fractures around the sites that are routinely fixed by bicortical K wires. If a fracture's location or configuration requires K-wire insertion angles $<45^\circ$, it is

Fig. 3 Example of how the distance between the starting point of the pin and horizontal distance (*D*) to the opposite cortex is calculated. Note the medial wire had skidded on the opposite cortex and a second wire from lateral was needed to stabilise the construction

Fig. 4 Wire before driving in at 40° (a), skid on endosteum at that degree (b) and penetration achieved at 50° (c)

better to change the surgical plan. To achieve high insertion angles, the near cortex entrance point of the wire could be drawn nearer to the fracture site, or the fixation device preference could be changed.

The study provided evidence that changing the diameter of the K wires between 1.5 and 2.2 mm does not influence penetration angle of the opposite cortices. In the literature search, we found no information about the influence of K-wire diameter on their elasticity and thus on their bone-penetration angles. However, basic science of biomaterials reveals that stiffness of the given cylindrical structures directly differs with the square of the changes in their radii [14]. Supported by this basic rule, in clinical practice when a fine K wire shows a tendency to bending and skidding over an opposite cortex, it is replaced by a thicker one. In this study, clinically, the most frequently used diameters of K wires were tested. Surprisingly, all these K wires with various diameters could perforate far cortices at similar angles. One reason for this similarity may be the small difference among diameters of the K-wire groups. We think that if we had used more distinct diameter pins (i.e. 1.0 and 2.5) we might obtain statistically significant differences.

The study also revealed that drilling speed has no significant effect on K-wire trans-cortex penetration angles. In their biomechanical study, Namba et al. [7] showed that drilling speed changes the pullout loads of the wires. According to them, alignment of the holes in near and far

cortices changes with drilling speed. High-speed drilling creates holes in one axis, whereas holes drilled at low speed might not be aligned. The authors concluded that misalignment of the holes created by low-speed drilling is the reason for higher pullout loads. It is obvious that misalignment of the holes in opposing cortices can only occur if wire direction changes after passing the proximal cortex. In this study, K-wires were passed using two different drilling speeds. Our results, unlike those of Namba et al. did not support any evidence that changes in drilling speed significantly affect K-wire direction when they pass across cortices. The reason for this inconsistency might be neutralisation of the effect of the near cortex in our study. On the other hand, it could be argued that the near cortices hold the wires more strongly than the bolts. If this is true, then contrary to our results, changes in drilling speed should lead to more changes in wire direction and consequently significant difference in K-wire penetration angles before trans-cortex engagement.

Another result of this study is that driving speed and strength applied by different surgeons does not significantly change opposite cortex penetration angles of K wires. In previously published biomechanical studies studying pull-out strength of K wires, constant driving speeds (i.e. feed rate 1.52 mm/s) were used [7, 8, 15]. We think this method cannot represent the situation in the operating room because every hand holding the drill exerts individual power and

Table 1 Values of perforation angles achieved by all studied wire diameters at two different drilling speeds by three surgeons

DIA	RPM	Senior resident		Junior specialist		Senior specialist	
		Median	Min-Max	Median	Min-Max	Median	Min-Max
1.5	400	50	45–55	50	45–60	50	45–50
	1300	50	45–55	50	40–55	45	45–50
1.8	400	50	45–55	45	45–55	50	45–50
	1,300	50	45–50	50	45–50	45	40–50
2.0	400	50	45–55	50	45–50	50	45–55
	1,300	50	45–50	50	45–55	50	45–50
2.2	400	45	45–50	50	45–50	50	45–50
	1,300	45	45–50	50	45–50	50	45–50

driving speed and would affect most biomechanical situations. To take into account the effect of changing hands, our study was performed by three different surgeons. Two were specialists [one senior (MME) and one junior (MC)] and the other was a senior resident (BG). Although the maximum drilling speed provided by the powered drill was constant, each surgeon performed the tests at his personal driving speed and strength. This variability in driving speed and strength did not reveal significant difference in penetration angles. On the other hand, this might be accepted as a sign of consistency of the methodology of the study.

The study had its drawbacks; perhaps the most important were uncontrolled changes in working length of the K wires and lack of study on K wires with pin-tip configurations other than the standard trocar tip. Working length was considered as the length of the wire piece from the closest bolt to the bone, which varied concomitantly with changes in the insertion angles. This issue was an uncontrolled variable due to study and frame design. Although elasticity of a material is known to be proportional to its working length [14], in our study, changes in working length did not lead to significant differences in result. We think that changes in working lengths might remain too small to lead to significant change in elasticity. The other drawback was the inability to use various wire-tip designs. In the literature, bayonet-tip K wires are reported to be useful where oblique applications, such as bone transport with circular external fixation, are necessary. In their biomechanical studies, Graebe et al. [8] and Zohman et al. [15] reported that high rake-angle trochar-point wires permit wider arc of approaches to the near cortex for penetration. Thus, the magnitude of tip rake angle of a K wire might also change penetration capability and angle on opposite cortices. It seems that penetration capability of a K wire on the near cortex have less clinical significance as we can create small cracks or aim the wire at higher angles and then direct the wire in desired directions. The main question remains the effect of pin-tip configuration on opposite-cortex penetration angle where there is no way to adjust the direction of a K wire. Because in this study we could not access officially registered K wires with different tip configurations, such as bayonet or diamond types, we studied only the most widely used standard trocar-tip K wires with 20° of tip-rake angle. We also had difficulty finding trocar tip wires with documented material and production specifications. This may be the result of manufacturers' policies, which mostly are oriented towards complex and expensive devices rather than commonly used cheap but cost-effective ones, such as K wires. We think the effect of wire-tip configuration and rake angle on opposite-cortex penetration angle is worth further study.

In conclusion, we propose that fractures around the sites routinely fixed by bicortical application of K wires should be evaluated preoperatively. If this evaluation reveals a need for oblique K-wire insertion angle <45°, a standard trocar-tip K-wire application would lead to wire tip slippage on the endosteal surface of the opposite cortex. As this leads to insufficient fixation stability, changes in the operative plan might be necessary.

Acknowledgement K wires used in this study were donated by Ortopro, Izmir, Türkiye. Sheep bones were supplied from Dervisoglu butcher (Mersin, Türkiye). Special thanks to Helfer Makina (Mersin, Türkiye) employees for their technical support.

Conflict of interest statement All authors declare that they have no conflict of interest.

References

1. Vatansever A, Piskin A, Kayalar M, Bal E, Ada S (2007) The effect of dorsal cortical comminution on radiographic results of unstable distal radius fractures treated with closed reduction and K-wire fixation. *Acta Orthop Traumatol Turc* 41:202–206
2. Szyluk K, Jasinski A, Koczy B, Widuchowski W, Widuchowski J (2007) Results of operative treatment of unstable distal radius fractures using percutaneous K wire fixation. *Ortop Traumatol Rehabil* 9:511–519
3. Gurkan V, Orhun H, Akca O, Ercan T, Ozel S (2008) Treatment of pediatric displaced supracondylar humerus fractures by fixation with two cross K-wires following reduction achieved after cutting the triceps muscle in a reverse V-shape. *Acta Orthop Traumatol Turc* 42:154–160
4. Zions LE, Woodson CJ, Manjra N, Zalavras C (2009) Time of return of elbow motion after percutaneous pinning of pediatric supracondylar humerus fractures. *Clin Orthop Relat Res* 467:2007–2010
5. Parmaksizoglu AS, Ozkaya U, Bilgili F, Sayin E, Kabukcuoglu Y (2009) Closed reduction of the pediatric supracondylar humerus fractures: the "joystick" method. *Arch Orthop Trauma Surg* 129:1225–1231
6. Magovern B, Ramsey ML (2008) Percutaneous fixation of proximal humerus fractures. *Orthop Clin North Am* 39:405–416
7. Namba RS, Kabo JM, Meals RA (1987) Biomechanical effects of point configuration in Kirschner-wire fixation. *Clin Orthop Relat Res* 214:19–22
8. Graebe A, Tsenter M, Kabo JM, Meals RA (1992) Biomechanical effects of a new point configuration and a modified cross-sectional configuration in Kirschner-wire fixation. *Clin Orthop Relat Res* 283:292–295
9. Sankar WN, Hebela NM, Skaggs DL, Flynn JM (2007) Loss of pin fixation in displaced supracondylar humeral fractures in children: causes and prevention. *J Bone Joint Surg Am* 89:713–717
10. Habernek H, Weinstabl R, Fialka C, Schmid L (1994) Unstable distal radius fractures treated by modified Kirschner wire pinning: anatomic considerations, technique, and results. *J Trauma* 36:83–88
11. Strohm PC, Muller CA, Boll T, Pfister U (2004) Two procedures for Kirschner wire osteosynthesis of distal radial fractures. A randomized trial. *J Bone Joint Surg Am* 86:2621–2628

12. Zions LE, McKellop HA, Hathaway R (1994) Torsional strength of pin configurations used to fix supracondylar fractures of the humerus in children. *J Bone Joint Surg Am* 76:253–256
13. Topping RE, Blanco JS, Davis TJ (1995) Clinical evaluation of crossed-pin versus lateral-pin fixation in displaced supracondylar humerus fractures. *J Pediatr Orthop* 15:435–439
14. Mow VC, Flatow EL, Ateshian GA (2000) Mechanical properties of materials. In: Buckwalter JA, Einhorn TA, Simon SR (eds) *Orthopaedic Basic Science*, 2nd edn. AAOS, Illinois, pp 133–180
15. Zohman GL, Tsenter M, Kabo JM, Meals RA (1992) Biomechanical comparisons of unidirectional and bidirectional Kirschner-wire insertion. *Clin Orthop Relat Res* 284:299–302