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EXPERIMENTAL LAB RESEARCH

WILEY

The effect of grip location on Kirschner wire bend characteristics: An in vitro study

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Abstract

Objective: To determine the effect of Kirschner wire (K-wire) grip location on bend angle, bend radius, and torque when performing a Z-bend technique.

Study design: Experimental study.

Sample population: Ten samples at each of five grip locations for each of three K-wire diameters.

Methods: K-wires of three diameters (0.9, 1.1, 1.6 mm) were drilled into PVC pipe, and a Jacob's chuck was used to bend the wires at five periodic grip locations (distance from the bone model). Torque, bend angle, and bend radius were determined for each sample. Outcome variables were statistically analyzed by grip location to determine significant relationships.

Results: A grip location of 2.0 cm in the 0.9 mm K-wire group minimized bend angle (mean ± SD: 75.92° ± 0.81) and bend radius (2.89 mm ± 0.08). A grip location of 3.0 cm in the 1.1 mm K-wire group minimized bend angle (72.88° ± 0.98) and bend radius (2.47 mm ± 0.20). A grip location of 3.0 cm minimized bend angle (74.38° ± 1.93) and bend radius (2.71 mm ± 0.27) in the 1.6 mm K-wire group. Torque at these grip locations for the 0.9, 1.1, and 1.6 mm K-wires was 6.50 N-m ± 0.0, 11.00 N-m ± 0.0, and 19.05 N-m ± 0.16, respectively.

Conclusion: Bend angle and bend radius can be minimized by bending K-wires at specific grip locations, though torque is not minimized at these locations.

Clinical significance

These findings provide an evidence-based recommendation of where surgeons should grip K-wires when bending them.

1 | INTRODUCTION

Kirschner wires (K-wires) have various applications in many veterinary and human orthopedic procedures.[1–3] They are commonly used to stabilize the tibial tuberosity following transposition as part of patellar luxation correction,[4,5] primary fixation during Salter Harris fracture reduction,[1,4,6–8] imparting additional stability for humeral condyle fracture fixation,[1,4,9] and as part of tension band constructs in opposing tensile forces across an osteotomy or fracture site.[10–12] After placement, these

The results of this project were presented at the sixth World Veterinary Orthopaedic Congress in Snowmass, Colorado on February 9, 2022.

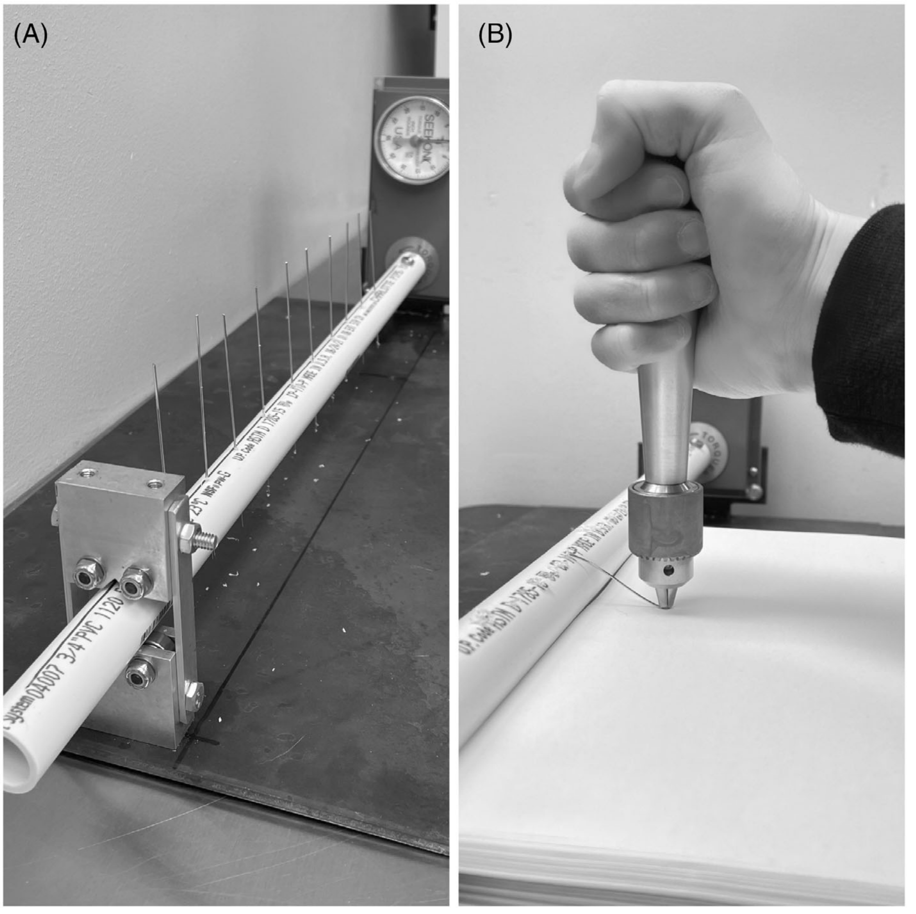

FIGURE 1 (A) Benchtop apparatus demonstrating 10 0.9 mm K-wires drilled into a 1.9 cm Charlotte PVC pipe (simulating bone in vivo) attached to a torquemeter. (B) A ream of paper acted as a uniform cessation point 1.9 cm below the bone model fulcrum, simulating soft tissue interference

implants are either cut flush with the bone or bent with the ends turned aside to avoid complications associated with adjacent anatomy.[1,8,10,13]

Complications related to K-wire application have been documented in human and veterinary literature, with their incidence ranging from 5% to 38%.[5,14–19] Kirschner wires are prone to migration, resulting in loss of fixation.[9,16,17] Additionally, protrusion of K-wires into surrounding extra-articular soft tissues may cause local irritation[14,15,17–22] and seroma formation[14–16,18,19,21] as well as persistent lameness due to entrapped soft tissues during placement.[11,14,15,18–20] Although there are reports recommending bending of K-wires to limit complications[9,10,13,22,23] and suggesting anecdotal recommendations of bending technique to prevent prominence and K-wire migration,[22,23] the biomechanics of these methods have not been demonstrated or studied. Clinically, a "Z-bend" technique, resulting in two bends, has been used to achieve a low-profile bend at the bone surface, although alternate bending methods of K-wire bending including a single 90° bend, use of a bending sleeve, or use of a K-wire bending tool have also anecdotally been used. The authors know of no studies investigating the biomechanics of K-wire bending to determine the optimal grip location from the fulcrum that will allow the K-wire to be placed flush with the contour of the bone while minimizing bending forces.

The objective of this study was to determine the optimal K-wire grip location when performing a Z-bend, such that bend angle, radius, and torque were minimized. We hypothesized that there would be a grip location that optimized bend angle and radius for each K-wire diameter. Additionally, we hypothesized that K-wire-bending torque would decrease as grip location, away from the fulcrum, increased.

2 | MATERIALS AND METHODS

A testing apparatus consisting of a torquemeter (TA-30, Seekonik Precision Tools, Seekonk, Massachusetts) connected to 1.9 cm PVC pipe to simulate a bone model was assembled (Figure 1A). A bending cessation point of 1.9 cm below the bone model fulcrum was used to simulate soft tissue limitations (Figure 1B). For small grip distances, such that the chucked end of the wire could not touch the limit, bending was stopped when the wire contacted the pipe. Kirschner wires (IMEX Veterinary Inc,

TABLE 1 Mean bend angle, bend radius, and torque values at incremental grip locations on Kirschner wires of various diameter

Wire size	Grip location (cm)	Bend angle (°)	± SD	Bend radius (mm)	± SD	Torque (N-m)	± SD
0.9 mm	1.0	89.31	2.45	3.86	0.32	7.70	0.26
	1.5	84.73	1.00	3.32	0.16	7.10	0.21
	2.0	75.92	0.81	2.89	0.08	6.50	0.00
	2.5	81.19	0.54	3.12	0.05	6.00	0.00
	3.0	87.83	0.71	3.68	0.07	5.50	0.00
1.1 mm	1.0	92.62	3.06	4.23	0.34	13.05	0.16
	2.0	79.95	1.28	3.08	0.09	10.05	0.16
	3.0	72.88	0.98	2.47	0.20	11.00	0.00
	4.0	79.83	0.79	3.09	0.05	7.00	0.00
	5.0	81.55	0.71	3.16	0.05	4.60	0.21
1.6 mm	3.0	74.38	1.93	2.71	0.27	19.05	0.16
	5.0	85.40	4.62	3.45	0.41	11.90	0.52
	7.0	93.20	3.89	4.48	0.64	10.15	0.24
	9.0	110.51	2.11	6.01	0.18	10.70	0.35
	11.0	113.29	0.94	6.21	0.08	10.40	0.21

Longview, Texas) of three diameters (0.9 mm, 1.1 mm, and 1.6 mm) were drilled into the PVC pipe using a battery-powered drill (6643, SmartDriver DUO, 6643–045 Automatic Wire Driver Coupler, MicroAire, Charlottesville, Virginia).

A pilot study was performed to determine a minimum grip location for each size wire such that bending was not possible at grip locations closer to the bone model: 0.9 mm at 1.0 cm, 1.1 mm at 1.0 cm, and 1.6 mm at 3.0 cm. Five incremental grip locations (0.9 mm, 0.5 cm increments; 1.1 mm, 1.0 cm increments; 1.6 mm, 2.0 cm increments) were evaluated for each diameter K-wire. A single investigator used a hand-held Jacob's chuck (30 002, IMEX Veterinary Inc) with a one-handed grip to manually bend the K-wires using a Z-bend technique until the cessation point was reached. Bending at each grip location for each K-wire diameter was repeated 10 times for a total of 50 samples for each K-wire diameter. Maximum torque values were recorded during each bend. Bend angle and radius at the bone model fulcrum were determined using digital photography and image processing software (vPOP^{PRO} version 2.3.0; VETSOS Education Ltd; https://vpop-pro.com).[24]

Statistical analysis reviewed means, medians, standard deviations, and plots to summarize the data and check for spurious observations. Plots of residuals from regression lines were used to identify linear relationships between grip location and torque, bend angle, and bend radius. Pearson's correlations were used to quantify the degree of the relationship between the linearly related variables and tested for statistical significance. Finally, nonlinear relationships among the variables were identified from graphs and commented on without statistical significance.

3 | RESULTS

Kirschner wire grip location had a significant effect on angle and radius for the 1.1 mm and 1.6 mm K-wire groups, but K-wire grip location was not linearly correlated with angle and radius for the 0.9 mm K-wire group (Table 1). Kirschner wire grip location had a significant effect on torque for all K-wire groups.

A grip location of 2.0 cm in the 0.9 mm K-wire group minimized bend angle (mean ± SD: 75.92° ± 0.81) and bend radius (2.89 mm ± 0.08) (Figure 2). A grip location of 3.0 cm in the 1.1 mm K-wire group minimized bend angle (72.88° ± 0.98) and bend radius (2.47 mm ± 0.20) (Figure 3). A grip location of 3.0 cm minimized bend angle (74.38° ± 1.93) and bend radius (2.71 mm ± 0.27) in the 1.6 mm K-wire group (Figure 4).

Torque had an inverse relationship to grip location in the 0.9 mm and 1.1 mm K-wire groups, but this relationship was not present in the 1.6 mm K-wire group. The torque at the optimal grip location (as defined by minimized bend angle and bend radius) for the 0.9 mm, 1.1 mm, and 1.6 mm K-wire groups were mean ± SD: 6.50 N-m ± 0.0, 11.00 N-m ± 0.0, and 19.05 N-m ± 0.16, respectively.

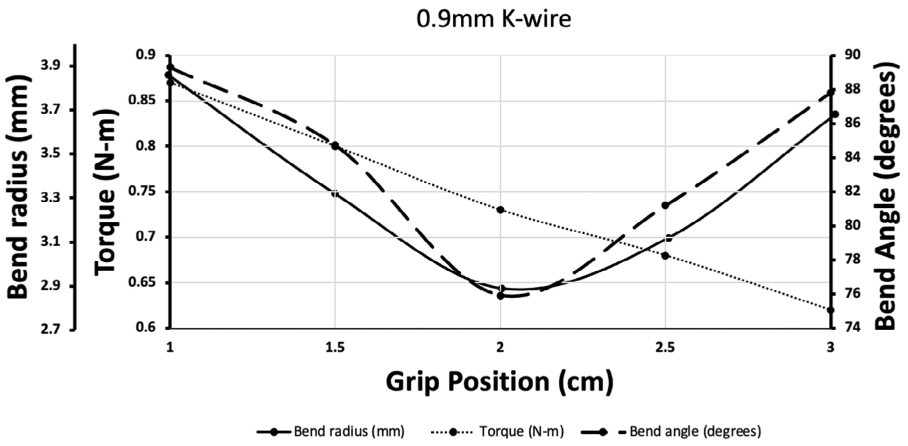

FIGURE 2 Relationship between grip location, bend angle, bend radius, and torque for 0.9 mm K-wires

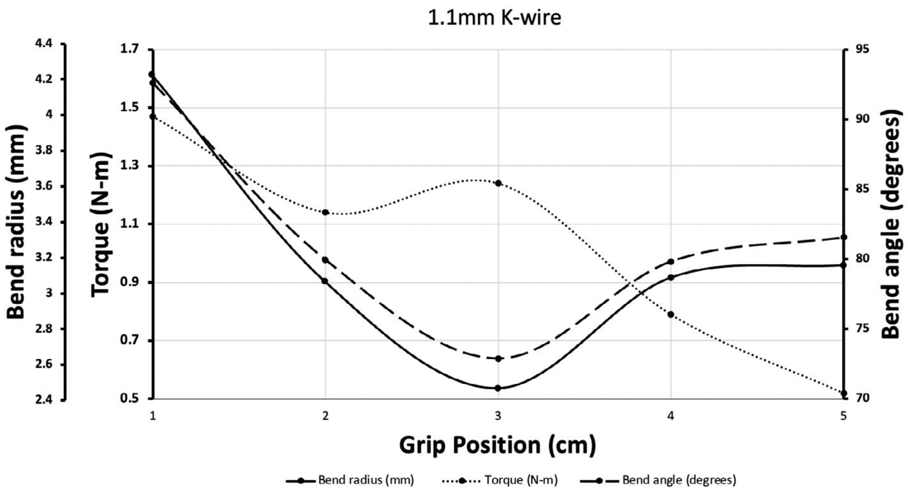

FIGURE 3 Relationship between grip location, bend angle, bend radius, and torque for 1.1 mm K-wires

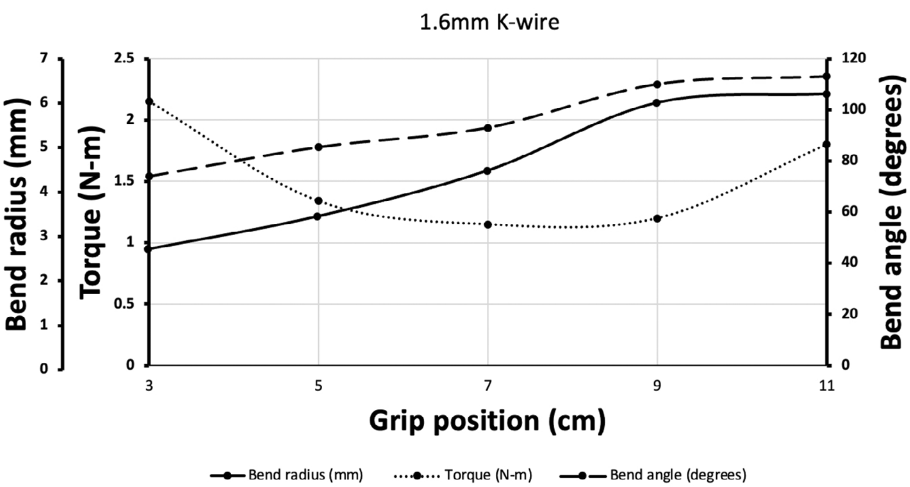

FIGURE 4 Relationship between grip location, bend angle, bend radius, and torque for 1.6 mm K-wires

4 | DISCUSSION

Theoretically, the optimal K-wire grip location when performing a Z-bend should minimize bend angle, bend radius, and torque. Based on our results this ideal grip location does not exist. Torque was highest at the lowest grip for all diameters (1.0 cm, 1.0 cm, and 3.0 cm respectively), while the grip location resulting in the lowest combination of bend angle and bend radius was 2.0 cm for the 0.9 mm group (Figure 2) and 3.0 cm for both the 1.1 mm and 1.6 mm groups (Figures 3 and 4). We accepted our hypothesis that there is a grip location that results in a more acute bend angle and smaller bend radius for each K-wire diameter. We also accepted our hypothesis that as grip distance from the fulcrum increases, maximum torque decreases; although an unexplained, and unlikely clinically relevant, exception to this was at the higher grip locations of 9.0 cm and 11.0 cm on the 1.6 mm wire.

The routine use of K-wires is complicated by the risk of soft tissue irritation if the ends are not seated or bent flush with the bone.[1,8,10,13] Protruding pins can entrap surrounding soft tissue structures, especially when used near joints with a large range of motion,[25] and can possibly exacerbate the chances of pin migration due to micromovement from soft tissues catching on the projected end. This may be because K-wires are inherently poor at resisting torsion and axial forces.[26] Therefore, it would be beneficial to aim for the lowest bend angle and radius possible to minimize the chance of soft tissue entrapment and subsequent opportunity for pin migration. We expected the lowest radius and angle to be achieved at the lowest grip location. This assumption was correct for the 1.6 mm diameter K-wires. It is not clear why this relationship was not present for the smaller K-wires; both had an angle and radius nadir at higher grip locations.

Although we identified grip locations that consistently minimized bend angle and bend radius in an in vitro model, it is possible that soft tissue structures will compromise a surgeon's ability to perform the bend when gripping the K-wire at these prescribed locations. In such cases, performing the Z-bend in the direction with the least soft tissue impedance and then maneuvering the K-wires into the desired orientation may allow for surgeons to minimize bend angle and bend radius. However, we attempted to mimic the impact of soft tissues by setting a consistent bending cessation point for all K-wire samples.

The theoretical K-wire bending torque is constant for each diameter, regardless of grip location. That our data did not follow this theoretical relationship is probably due to the more complex forces involved in a Z-bend versus pure cantilever bending. Clinically safe torque values are not known and probably differ based on application and patient factors Although lower torque is logically preferred, the torque associated with the optimal grip locations in this study may be clinically safe. Surgeons should use the results of this study to balance the risk of pin-tip complications with those of fixation disruption or bone damage due to high bending torque.

There are currently no established guidelines describing K-wire bending techniques in human or veterinary clinical practice. Firoozabadi and colleagues recommended bending K-wires into a hook-like formation with the free end of the wire embedded into bone to avoid postoperative complications.[22] However, the results from their case series were strictly subjective as no measurements or statistical analyses were performed to support their recommendation. We believe our data may be the first to offer an objective approach to K-wire bending techniques, although our results are limited to the Z-bend technique only.

Previous reports and anecdote suggest that clinicians use multiple instruments, such as the IMEX K-wire bender, Frazier suction tip,[22] or K-wire drill coupler to bend K-wires. Although we used a handheld Jacob's chuck to produce repeatable results without requiring specialized instrumentation, it is possible that alternate instrumentation may complicate a clinician's ability to perform a Z-bend technique at a specific grip location.

Our study has limitations associated with in vitro testing and results should be interpreted within that context. Although we only used K-wires from a single manufacturer, they were made from medical grade 316 L stainless steel and of standard sizes, so the results are unlikely to be changed with K-wires from additional sources. Additionally, though our in vitro study investigates an optimal grip location to minimize bend angle, bend radius, and torque, the impact of minimizing these metrics is unknown in a clinical setting. Further, it is likely that other factors may contribute to K-wire complications, and added study into the effects of different methods used to cut K-wires, producing a sharp or flat end, or identifying an optimal remainder length of the post-bend protruding K-wire are recommended.

The clinical relevance of our study could be improved with further research into safety of torque applied to bone or demonstration of in vivo reliability by assessing complication rates associated with our proposed grip locations. In conclusion, due to the dearth of current evidence and lack of consensus in clinical practice of optimal grip location, the findings of this study offer valuable insight that may be used to aid clinical decision making and guide areas of future investigation.

AUTHOR CONTRIBUTIONS

Gremley JR, MPH, DVM: Contributed to the acquisition and interpretation of data as well as authoring the manuscript. Frederick SW, RVT, VTS (Surgery): Contributed to study design, data analysis and interpretation as well as authoring the manuscript. Cross AR, DVM, DACVS: Designed the project, constructed the apparatus and contributed to the authoring of the manuscript.

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CONFLICT OF INTEREST

The authors have no conflict of interested related to this report.

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