Surgery Article

HAND
2018, Vol. 13(4) 423–427

DOI: 10.1177/1558944717708052
hand.sagepub.com

Temperature Rise in Kirschner Wires Inserted Using Two Drilling Methods: Forward and Oscillation

Scott Richard Anderson[1], Serkan Inceoglu[1], and Montri D. Wongworawat[1]

Abstract

Background: Kirschner wires (K-wires) are commonly used in orthopedic surgery. However, the loosening of the pins can lead to delayed or improper healing or infection. Wire loosening can occur by thermal necrosis that occurs due to heat produced during wire insertion. Although the parameters that affect temperature rise in cortical bone during wire insertion and drilling have been studied, the effect of drilling mode (oscillation versus forward) is unknown. The purpose of this study was to compare the temperature changes occurring in cortical bone during wire insertions by oscillating and forward drills. Our hypothesis is that oscillation drilling would produce less heat compared with forward drilling in K-wire insertion with 2 commonly used wire diameters. **Methods:** We drilled K-wires in a pig metacarpal model and measured the temperature rise between forward and oscillation drilling modes using diamond-tipped 0.062- and 0.045-inch-diameter K-wires. There were 20 holes drilled for each group (n = 20). **Results:** The average temperature rise using the 0.062-inch K-wire under forward and oscillation insertion was 14.0 ± 5.5°C and 8.8 ± 2.6°C, respectively. For the 0.045-inch K-wire, under forward and oscillation insertion, the average temperature rise was 11.4 ± 2.6°C and 7.1 ± 1.9°C, respectively. The effects of the drilling mode and wire diameter on temperature rise were significant ($P < .05$). **Conclusions:** In conclusion, the oscillation of K-wires during insertion causes a lower temperature rise when compared with forward drilling.

Keywords: temperature, Kirschner wire, K-wire, drilling, oscillation, forward, unidirectional, bidirectional, osteonecrosis

Introduction

Kirschner wires (K-wires) are commonly used in orthopedic surgery due to their ease of insertion and minimal invasiveness. They are commonly used for fractures of the hand, wrist, and pediatric elbow. However, loosening of the pins can lead to delayed or improper healing or infection.[4,11]

Wire loosening can arise from thermal necrosis, which is associated with heat produced during drilling or wire insertion.[5,6,15] The thermal necrosis entails reduction in osteocytes, reduces osseous blood flow, and increases osteoclast activity.[3] It is an irreversible insult that has been shown to result in poor healing potential. It is often observed in the percutaneous insertion of K-wires,[8] where local temperature can exceed 47°C.[7,11] K-wire temperatures with a single pass have been reported as high as 115°C[14] and can heat up surround tissues in the human finger up to 190°C.[17]

Several studies have identified significant factors that can decrease temperature and in turn can decrease the rate of thermal injury.[2,9,10,14] These changes include alternative drill tip designs, external cooling irrigation, and pneumatic hammering of K-wires into bone. These technologies are not typically available at most surgery centers. On the contrary, commonly used standard surgical drills have been recently improved to provide an oscillation mode. The oscillating drilling has been shown to require less force[12] and also protect surrounding soft tissue structures. However, it still remains unknown whether these drills may have the additional advantage of producing less heat. We therefore set out to compare the temperature rise occurring during wire insertion into cortical bone in oscillation mode and forward mode using wires with 2 commonly preferred diameters. Our hypothesis was that oscillation mode

[1]Loma Linda University, CA, USA

Corresponding Author:
Montri D. Wongworawat, Professor, Head of Orthopeadic Hand Surgery, Department of Orthopaedic Surgery, Loma Linda University Medical Center, 11406 Loma Linda Drive, Suite 218, Loma Linda, CA 92354, USA.
Email: dwongworawat@llu.edu

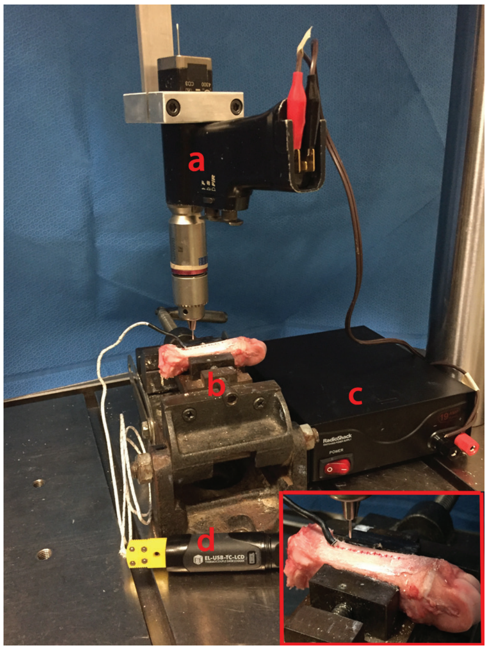

Figure 1. Drill setup.
Note. The drill (a) is mounted to the Instron via a custom-made attachment that allows for the controlled advancement and retraction of the drill. The drill is than advanced using the Instron to the metacarpal (b) once the external power source (c) is activated. The temperature is recorded by the thermocouple (d). The zoomed caption demonstrates the thermocouple in one of the predrilled holes and the Kirschner wire starting points measured on the dorsal surface.

would produce less heat regardless of the size of the wire diameter.

Materials and Methods

Bone Preparation

Five fresh-frozen pig feet were obtained for this project. Specimens were thawed at room temperature (23°C) for cleaning. Once at room temperature, the specimens were dissected and the second and third metacarpals were harvested and stripped of soft tissue for a total of 10 denuded pig metacarpals. The individual metacarpals were then fixed securely on a miniature portable vise. Four holes with 1-mm diameter were drilled unicortically over the dorsal cortex with 7-mm distance in between to accommodate the sensing tip of the thermocouple (Lascar EL-USB-TC; Lascar Electronics Inc, Erie, Pennsylvania). Preliminary dissections showed that the dorsal cortex had consistent thickness (1.7-3 mm). Two marks were placed 1 mm from the thermocouple hole centered and in line with the longitudinal axis of the bone for drilling. The thermocouple hole was then filled with thermally conductive silicone paste to aid in the temperature recording of the surrounding bone (Figure 1).

Drilling and Temperature Recording

A total of 10 pig metacarpal bones were used. There were 20 drill insertions made with each drill direction and each wire diameter, totaling 80 drill holes in the entire study.

The vise holding the specimens was secured into a universal materials testing machine (Instron Inc, Norwood, Massachusetts). A standard surgical drill (Stryker Cordless Driver 3; Stryker Corporation, Kalamazoo, Michigan) was attached to the load cell and actuator of the machine via a custom-made adapter. The actuator was lowered to the specimen until the tip of the drill was barely making contact with bone at the premarked point.

The starting temperature of the samples was recorded to be 23°C prior to drilling. Following this, the drill was powered up and actuator drove the drill into the specimen at a rate of 0.5 mm/s and retracted at the same rate after 10 mm of advancement without pausing. After moving the specimen to the next marked point, the drill was switched to other drilling mode and the test was repeated. The order of drill mode was altered at each measurement point to prevent any test order–related bias. Wires were replaced after every third pass. An external power source was connected to the drill, preventing speed variations caused by battery drain. The forward and oscillation speeds were recorded using a high-speed camera and measured to be approximately 560 revolutions per minute (RPM) and 300 RPM, respectively.

We measured the temperature rise difference between forward and oscillation modes with diamond-tipped 0.062- and 0.045-inch-diameter K-wires (Zimmer Inc, Warsaw, Indiana) using 5 specimens and 20 holes for each group ($n = 20$). All testing was performed at room temperature. A steady state temperature was recorded prior to initiation of drilling. The thermocouple recorded temperature measurements at 1-second intervals. Change in temperature was recorded for each drilling. (Table 1)

Postdrilling Measurements

Following the completion of the drilling, the distance from the thermocouple hole to the wire insertion site (ie, thickness of the bone bridge between holes) was recorded using a digital caliper. The specimens were then split along the longitudinal axis, and the cortical thickness at each of the drilling sites was also recorded (Figure 2).

Data Analysis

A 2-way analysis of covariance (ANCOVA) was performed to determine statistically significant differences both between drilling modes (oscillating and forward) and between K-wire diameters (0.062 and 0.045 inch) on the temperature measurement as well as their interactions while

Table 1. Descriptive Statistics.

Kirschner wire diameter (inch × 1000)	Drilling mode	Measurement	n	Minimum	Maximum	Mean	Standard deviation
6.2	Forward	Distance (mm)	20	0.6	1.3	0.91	0.20749
		Depth (mm)	20	1.8	3	2.3475	0.32746
		Temperature (°C)	20	4	22	14.025*	5.52619
	Oscillation	Distance (mm)	20	0.6	1.3	0.865	0.19808
		Depth (mm)	20	1.8	3	2.348	0.32746
		Temp (°C)	20	3.5	12.5	8.75*	2.55724
4.5	Forward	Distance (mm)	20	0.6	1.1	0.89	0.13338
		Depth (mm)	20	1.7	2.5	2	0.18918
		Temperature (°C)	20	8	16	11.35*	2.57058
	Oscillation	Distance (mm)	20	0.7	1.1	0.915	0.09881
		Depth (mm)	20	1.7	2.5	2	0.18918
		Temperature (°C)	20	2.5	10	7.075*	1.90066

*$P < .05$.

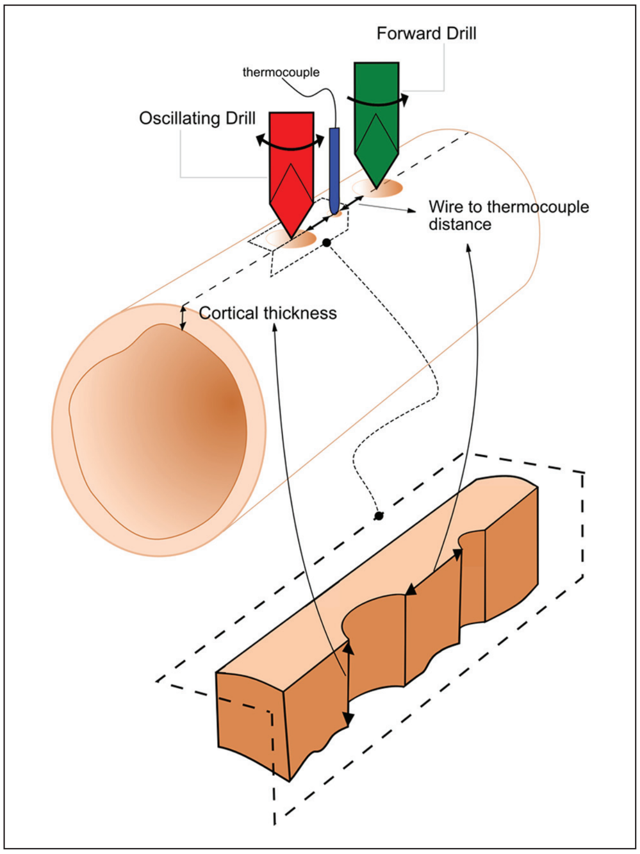

Figure 2. Measurement diagram. This diagram shows the measurements used for the Kirschner wire start point in relation to the thermocouple and the cortical thickness.

controlling for the distance of the thermocouple to the drill bit, thereby eliminating its influence on the temperature measurement. The cortical thickness was found to have a negligible and insignificant ($P = .26$) effect on the temperature change, and thus, it was not included as a covariate.

Results

ANCOVA test showed that there was significantly higher temperature change in forward drill mode ($P < .001$) and larger wire diameter ($P < .001$) after controlling for the drill-to-thermocouple distance. The average temperature rise using the 0.062-inch K-wire under forward and oscillation insertion was 14.0 ± 5.5°C and 8.8 ± 2.6°C, respectively, with a mean difference of 5.2°C. For the 0.045-inch K-wire, under forward and oscillation insertion, the average temperature rise was 11.4 ± 2.6°C and 7.1 ± 1.9°C, respectively, with a mean difference of 4.5°C. The thermocouple-to-wire distances for the 0.062-inch wire were 0.91 ± 0.21 mm and 0.87 ± 0.19 mm under forward and oscillation modes, respectively, which were not significantly different ($P = .51$). The thermocouple-to-wire distances for the 0.045-inch K-wire were 0.89 ± 0.13 mm and 0.92 ± 0.09 mm under forward and oscillation modes, respectively, which were not significantly different ($P = .49$). The cortical thickness of insertion was an average of 2.35 ± 0.32 mm (1.8-3 mm) and 2 ± 0.19 mm (1.7-2.5 mm) for the 0.062- and 0.045-inch K-wires, respectively, which were significantly different ($P < .01$).

Discussion

Kirschner wires are commonly used in orthopedic surgery for fracture fixation. However, during insertion, temperatures can exceed 47°C, which can lead to osteonecrosis.[7,11] This may lead to loosening of the pins and thus delayed or improper healing and infection.[4] Newer surgical drills employ oscillation, thereby requiring less force[12] and protecting surrounding soft tissue structures. Our study showed there was a less temperature rise when using the drill in oscillation which may impact the degree of thermal necrosis that occurs around the K-wire insertion site.

Kirschner wires have been found to produce significantly higher temperatures than drill bits of the same diameter.[13] This is likely due to the lack of flutes to clear debris, which increases temperature.[18] In addition, it has been found that multiple passes through the same area of bone cause an increased accumulation of heat.[13] This is a scenario typically encountered in clinical practice during fracture fixation. Our study did not measure this effect, but there may have been an even higher rise in temperature.

We found that the use of a wire with a smaller diameter helped decrease heat generated during wire insertion, which agreed with prior studies, where smaller drill bits were linked to lower temperatures.[2] This finding is intuitive because the smaller the diameter, the smaller the surface area, and thus the less the frictional forces.

Our study has some limitations. Our study was performed in laboratory conditions at a room and a bone temperature of 23°C. Although we did not record drilling temperatures at 37°C (body temperature), Sedlin and Hirsch demonstrated that the physical properties of bone at room temperature were comparable with those at body temperature.[1] Therefore, we used a minimum temperature rise of 10°C from body temperature as the threshold for thermal osteonecrosis. This occurred with both K-wire diameters in forward but not oscillation. In addition, we were not able to obtain a recording directly at the insertion site that might have had a higher temperature measurement than where we were recording. In surgery, the wire and hole are engulfed by blood and soft tissue in some cases, which both could affect the dissipation or damping of the heat generated due to friction. Although the pig model closely mimics the human bone,[1] we do not know how age-related changes in human bone will influence the heat generated by the wire. For the effect of wire size, we choose only 2 most commonly used diameters from a large spectrum of wire diameters, that is, wires as large as Steinmann pins. Based on 2 diameters, we cannot confidently and reliably generalize our findings on all other wire sizes. Future studies are also necessary to determine the effect of the insertion of multiple K-wires at close proximity as seen in upper extremity fracture stabilization.

Conclusion

The oscillation of a K-wire yielded less heat when compared with forward drilling. In addition, K-wire diameter of 0.045 inch had less temperature rise with insertion compared with 0.062 inch with both oscillation and forward drilling.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

This article does not require the need for informed consent.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Two of the authors (S.R.A. and S.I.) declare that there is no conflict of interest. One of the authors (M.D.W.) has the following conflicts of interest to report: AAOS: Board or committee member; Alumni Association School of Medicine: Board or committee member; Association of Bone and Joint Surgeons: Board or committee member; Clinical Orthopaedics and Related Research: Editorial or governing board; Health Services International: Board or committee member; Neufeld Society (Alumni Association): Board or committee member; County Medical Society: Board or committee member.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Aerssens J, Boonen S, Lowet G, et al. Interspecies differences in bone composition, density, and quality: potential implications for in vivo bone research. *Endocrinology*. 1998;139(2):663-670.
2. Augustin G, Davila S, Mihoci K, et al. Thermal osteonecrosis and bone drilling parameters revisited. *Arch Orthop Trauma Surg*. 2008;128(1):71-77.
3. Baron R, Horne W. Bone resorption: regulation of osteoclast activity. In: Bronner F, Farach-Carson MC, eds. *Topics in Bone Biology*. London, England: Springer; 2005.
4. Botte MJ, Davis JL, Rose BA, et al. Complications of smooth pin fixation of fractures and dislocations in the hand and wrist. *Clin Orthop Relat Res*. 1992;276:194-201.
5. Brisman DL. The effect of speed, pressure, and time on bone temperature during the drilling of implant sites. *Int J Oral Maxillofac Implants*. 1996;11(1):35-37.
6. Eriksson RA, Adell R. Temperatures during drilling for the placement of implants using the osseointegration technique. *J Oral Maxillofac Surg*. 1986;44(1):4-7.
7. Eriksson RA, Albrektsson T, Magnusson B. Assessment of bone viability after heat trauma. A histological, histochemical and vital microscopic study in the rabbit. *Scand J Plast Reconstr Surg*. 1984;18(3):261-268.
8. Franssen BB, Schuurman AH, Brouha PC, et al. Hammering K-wires is superior to drilling with irrigation. *Hand (N Y)*. 2009;4(2):108-112.

9. Franssen BB, van Diest PJ, Schuurman AH, et al. Keeping osteocytes alive: a comparison of drilling and hammering K-wires into bone. *J Hand Surg Eur Vol*. 2008;33(3):363-368.
10. Matthews LS, Green CA, Goldstein SA. The thermal effects of skeletal fixation-pin insertion in bone. *J Bone Joint Surg Am*. 1984;66(7):1077-1083.
11. Matthews LS, Hirsch C. Temperatures measured in human cortical bone when drilling. *J Bone Joint Surg Am*. 1972;54(2):297-308.
12. Nichter LS, Richlin S, Navarrette PM, et al. The biomechanical efficacy of an oscillating K-wire driver. *Ann Plast Surg*. 1992;29(4):289-292.
13. Palmisano AC, Tai BL, Belmont B, et al. Heat accumulation during sequential cortical bone drilling. *J Orthop Res*. 2016;34(3):463-470.
14. Piska M, Yang L, Reed M, et al. Drilling efficiency and temperature elevation of three types of Kirschner-wire point. *J Bone Joint Surg Br*. 2002;84(1):137-140.
15. Reingewirtz Y, Szmukler-Moncler S, Senger B. Influence of different parameters on bone heating and drilling time in implantology. *Clin Oral Implants Res*. 1997;8(3):189-197.
16. Sedlin ED, Hirsch C. Factors affecting the determination of the physical properties of femoral cortical bone. *Acta Orthop Scand*. 1966;37(1):29-48.
17. van Egmond DB, Hovius SER, van der Meulen JC, et al. Heat recordings at tips of Kirschner wires during drilling through human phalanges. *J Hand Surg Am*. 1994;19(4):648-652.
18. Wiggins KL, Malkin S. Drilling of bone. *J Biomech*. 1976;9(9):553-559.