Thermal Effect of Cooling External Fixation Wires During Percutaneous Wire Placement

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Statement of Purpose

Orthopedic literature has shown that drill bits yield thermal necrosis as a result of temperature, duration, drilling speed, rate of advancement, wire tip design and material, and cooling methods (1-5). Percutaneous wires are an essential component of external fixation procedures. Accurate pin site fixation is critical for the stability and prevention of pin site infections. While few studies exist for wire drilling, the most commonly studied methods for cooling with drill bits or osteotomies are the use of both internal and external irrigation (6-7). However, due to the small diameter of external fixation wires and soft tissue coverage internal irrigation is not feasible (8). External irrigation is dependent on many factors including accessibility to the insertion or exit site, as well as constant flow which is often impractical with external fixation wire placement yielding loss of the cooling effect (7,9-10). The aim of this study is to identify the thermal effects of various wire cooling methods during or prior to percutaneous wire insertion.

Materials and Methods

Rigid Polyurethane Foam (RPF) sawbones were utilized to simulate cortical bone drilling with controlled thickness and density. The 20mm thickness was selected to mimic monocortical drilling without pause within the intramedullary canal, while the 10mm thickness was selected due to its clinical relevance for unicortical thickness. All densities were standardized at 50 PCF. A custom computerized drill (Smart Medical Devices, Inc. Las Vegas, NV, USA) enabled controlled drilling parameters (Figure 1). Stainless steel wires measuring 1.5mm in diameter with the ilizarov (eccentric) tip design were selected for this study. Wires were drilled 20mm beyond the depth of the sawbone thickness to obtain a 20mm plunge upon exit. A FLIR infrared thermography camera (Wilsonville, Oregon, USA) was used to record the thermal data (Figure 2). Wire cooling methods were tested with high thermal producing (HTP) and low thermal producing (LTP) drilling parameters defined as: HTP drilling parameters at 1000 RPM and 1.5 mm/sec feed rate and LTP drilling parameters at 600 RPM and 2.5 mm/sec feed rate.

The following outcomes were recorded:
1. Wire tip temperature at the exit point of the block
2. The maximum temperature recorded between wire exit & final resting position
3. The time the wire temperature was recorded above 47°C

Methods of wire cooling tested with HTP included:
1. (RT) Room temperature
2. (CS) Cooled saline solution bath refrigerated at -4°C with wires placed a minimum of 30 minutes prior to use
3. (SS) Surgical slush solution bath with wires placed a minimum of 30 minutes prior to use
4. (Frozen) Freezer placement at -20 °C for minimum 12 hours prior to use with room temperature exposure limited to less than two minutes prior to testing
5. (SG) Insertion through gauze soaked in room temperature saline solution
6. (AG) Insertion through gauze soaked in 99% isopropyl alcohol
7. (Frozen AG) Freezer placement of the wire, gauze, and 99% isopropyl alcohol at -20 °C. Frozen wire inserted through frozen gauze soaked in the cold isopropyl alcohol.

Methods of wire cooling tested with LTP included:
1. (RT) Room temperature
2. (Frozen) Freezer placement at -20 °C for minimum 12 hours prior to use with room temperature exposure limited to less than two minutes prior to testing
3. (AG) Insertion through gauze soaked in 99% isopropyl alcohol
4. (Oscillation) Room temperature oscillation drilling was tested with drilling for 2 mm followed by a sixty second stop for cooling. This was repeated until targeted distance was achieved.

Data was analyzed with the R statistical program. One-way ANOVA and Kruskal Walis tests were conducted with statistical significance ($p<0.05$). All data reported is mean ± standard deviation.

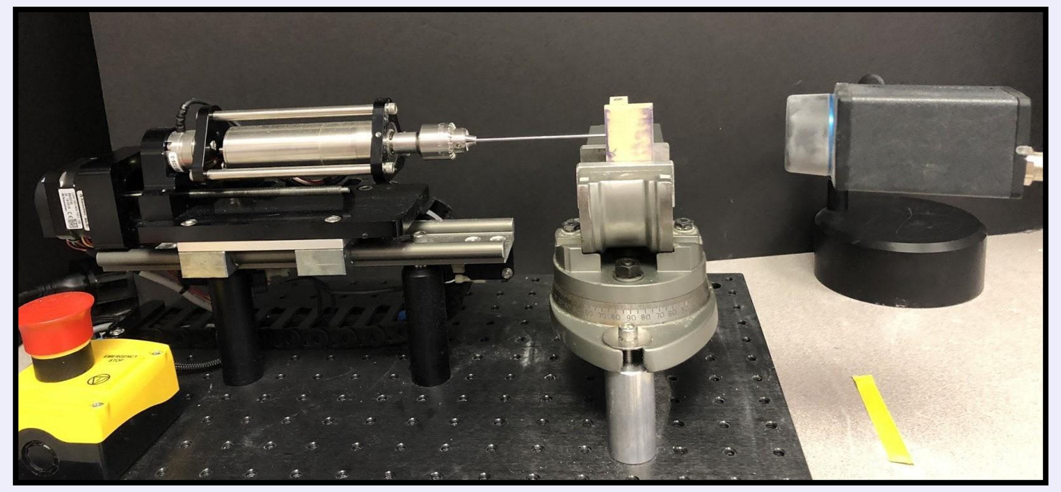

Figure 1: Laboratory set up for testing

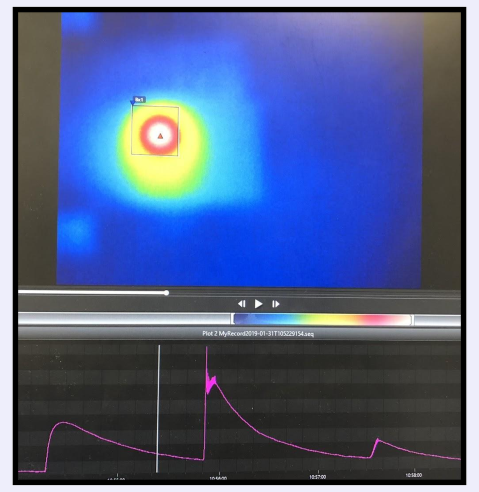

Figure 2: FLIR camera live recording of temperature

Results

The HTP drilling parameters mimicking monocortical drilling (20mm, 50PCF) showed the mean exit temperature with RT wires to be 53.83 ± 3.84 °C (range 48.2-60.1°C). This was statistically different as compared to SS (43.17 ± 4.14°C), frozen (40.24 ± 4.83°C), room temperature AG (42.04 ± 3.43°C), and frozen AG (45.53 ± 6.03°C) (Figure 3). However, these cooling techniques were not significant when compared to each other. The mean maximum temperature for HTP drilling with a RT wire was a startling 111.24 ± 7.11°C, demonstrating the significant heat production that can occur. This was again statistically significant as compared to SS, frozen, room temperature AG, and frozen AG. Room temperature AG demonstrated the lowest maximum temperature 84.39 ± 9.04 °C (Figure 3). Conversely, the time spent above 47°C was not stastically significant between any cooling method with room temperature 113 ± 10.59 seconds (Figure 4).

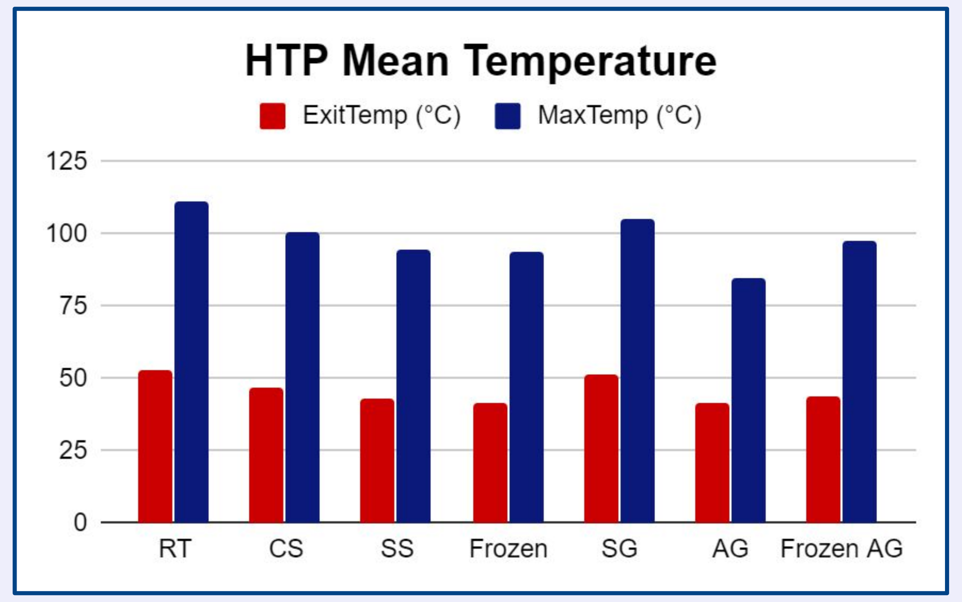

Figure 3: Mean exit and maximum temperatures with HTP method

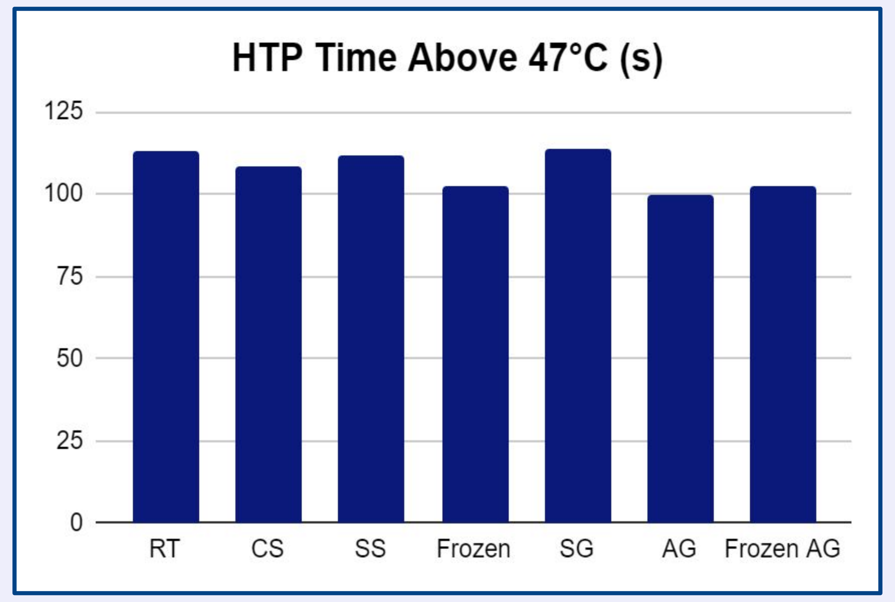

Figure 4: Mean time above 47°C with HTP method

Analyzing RT, frozen, AG, and oscillation with the LTP drilling parameters the mean exit temperature at room temperature was 48.61 ± 7.37°C. This was not significant as compared to any of the cooling methods or oscillation (Figure 5). However, the mean maximum temperature at RT of 73.28 ± 5.58°C was significantly different than oscillation which produced a maximum temperature of 55.6 ± 6.7°C (Figure 5). RT wire time spent above 47°C of 29.5 ± 4.97 seconds was significantly higher than frozen and oscillation with oscillation showing the lowest time of 5.5 ± 2.84 seconds (Figure 6).

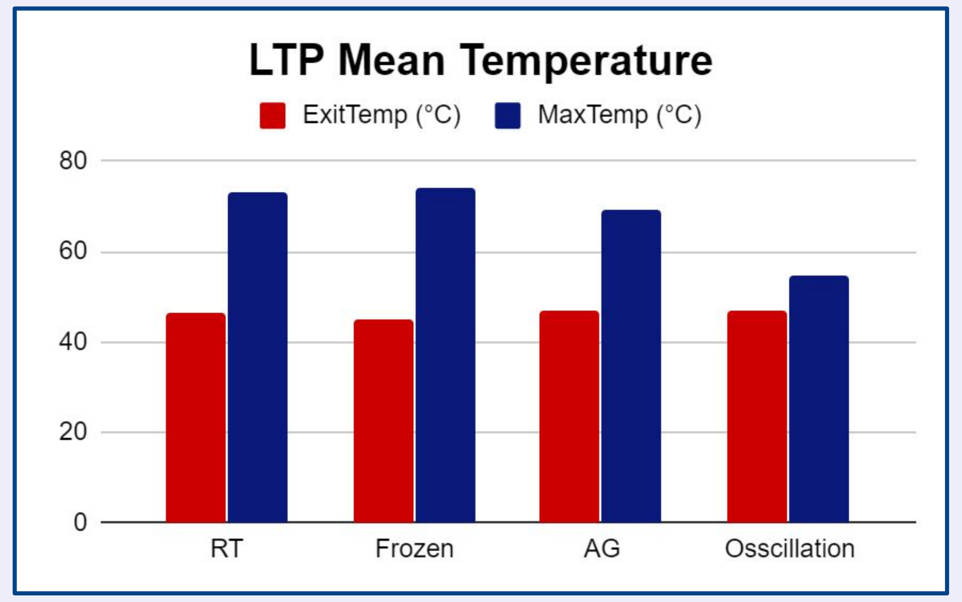

Figure 5: Mean exit and maximum temperatures with LTP method

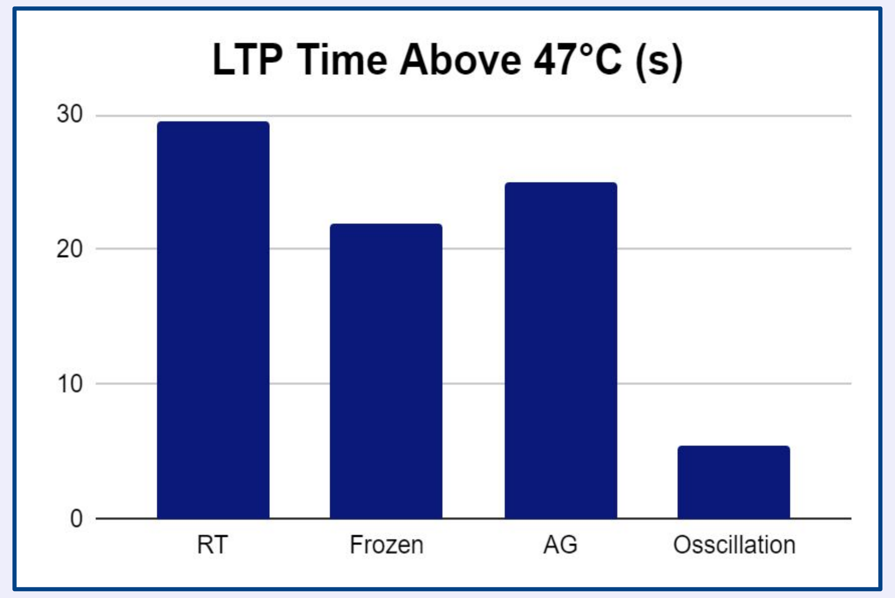

Figure 6: Mean time above 47°C with LTP method

Discussion

It is well understood that orthopedic surgical instrumentation yields heat that can cause thermal osteonecrosis (10-11). The current consensus in literature demonstrates that osteonecrosis occurs when bone is exposed to temperatures greater than 47°C for sixty seconds or longer (12). Implanted devices with surrounding osteonecrosis are exposed to necrotic tissue which may yield reduction in bone to implant incorporation (13-14). The risk of osteocutaneous thermal necrosis is higher in the lower extremity due to the anatomic considerations of thickness and density of cortical bone and soft tissue envelope (15). This is particularly important for consideration with external fixation application due to the importance of stability with each external fixation wire. Moroni et al. stated that the bone to pin interface is the site where the worst external fixation complications occur including pin loosening or infection (16). Literature has demonstrated the benefit of cooling drill bits with irrigation in order to lower the risk of thermal osteonecrosis, however this has not been fully studied with external fixation wire placement until now. Wire cooling methods demonstrated a small decrease in temperature with HTP drilling parameters at mimicked monocortical thickness in dense cortical bone. However, at optimal LTP producing drilling parameters with unicortical thickness there was no statistically significant change with wire cooling techniques. These results demonstrate that isolated wire cooling techniques do not provide a decrease in thermal production substantial enough to alter the degree of thermal osteonecrosis. The initial wire temperature from cooling methods does not reduce thermal damage to the degree that utilization of appropriate drilling parameters offers. In addition, oscillation techniques with drilling with frequent stops significantly decreases the temperature; however drilling two millimeters and then resting for 60 seconds may be impractical in the clinical setting.

Clinical Recommendations

1. Optimal drilling conditions include:
   - Lowest frequency of rotation
   - Highest rate of advancement
2. Avoid monocortical drilling to reduce thickness during drilling in cortically dense bone
3. Drill with frequent stops to decrease the distance travelled yielding lower thermal production
4. Avoid high frequency of rotation drilling through the intramedullary canal
5. Upon exiting the second cortex it is important to:
   - Stop drilling to avoid increasing heat production with RPM
   - Plunge through to exit the skin rather than tapping it through. This avoids allowing a heated wire to remain in the soft tissue for an extended period of time.
6. The initial wire temperature from cooling methods does not reduce thermal damage enough to prevent thermal osteonecrosis; utilizing appropriate drilling parameters is more important.

References

1. Berman AT, Reid JS, Yanicko DR, et al. Thermally induced bone necrosis in rabbits. Relation to implant failure in humans. Clin Orthop Relat Res 1984;186:284–92.
2. Abouzgia MB, James DF. Temperature rise during drilling through bone. Int J Oral Maxillofac Implants 1997;12:342–53.
3. Khanna A, Plessas SJ, Barrett P, et al. The thermal effects of Kirschner wire fixation on small bones. J Hand Surg [Br] 1999;24:355–7. doi:10.1054/jhsb.1998.0055.
4. 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;84:137–40. doi:10.1302/0301-620X.84B1.10692.
5. Lavelle C, Wedgwood D. Effect of internal irrigation on frictional heat generated from bone drilling. J Oral Surg 1980;38:499–503.
6. Matthews, L. S., & Hirsch, C. (1972). Temperatures measured in human cortical bone when drilling. *The Journal of Bone and Joint Surgery.American Volume, 54*(2), 297-308.
7. Yacker, M. J., & Klein, M. (1996). The effect of irrigation on osteotomy depth and bur diameter. *The International Journal of Oral & Maxillofacial Implants, 11*(5), 634-638.
8. Lavelle, C., & Wedgwood, D. (1980). Effect of internal irrigation on frictional heat generated from bone drilling. *Journal of Oral Surgery (American Dental Association : 1965), 38*(7), 499-503.
9. Wachter, R., & Stoll, P. (1991). Increase of temperature during osteotomy. in vitro and in vivo investigations. *International Journal of Oral and Maxillofacial Surgery, 20*(4), 245-249. doi:10.1016/s0901-5027(05)80185-7
10. Eriksson AR, Albrektsson T, Albrektsson B. Heat caused by drilling cortical bone. Temperature measured in vivo in patients and animals. Acta Orthop Scand 1984;55:629–31.
11. Lee, J.E., Rabin, Y., Ozdoganlar, O.B. A new thermal model for bone drilling with applications to orthopaedic surgery. Med Eng Phys 2011; 33: 1234-44 DOI:10.1016/j.medengphy.2011.05.014.
12. Lundskog, J. Heat and bone tissue. An experimental investigation of the thermal properties of bone and threshold levels for thermal injury. Scand J Plast Reconstr Surg1972; 9: 1-80
13. Tawy, Gwenllian F. and Rowe, Philip J. and Riches, Philip E. (2016) Thermal damage done to bone by burring and sawing with and without irrigation in knee arthroplasty. Journal of Arthroplasty, 31 (5). pp. 1102- 1108. ISSN 1532-8406 http://dx.doi.org/10.1016/j.arth.2015.11.002
14. Toksvig-Larson, S., Ryd ,L., Lindstrand, A. On the problem of heat generation in bone cutting. Studies on the effect of liquid cooling. J Bone Joint Surg 1991; 73-B: 13-5
15. Lovisetti G, Sala F, Thabet A, Catagni M, Singh S. Osteocutaneous thermal necrosis of the leg salvaged by TSH/Ilizarov reconstruction. International Orthopedics 2011; 35(1): 121-126. http://dx.doi.org/10.1007/s00264-010-0952-5
16. Moroni A, Vannini F, Mosca M, Giannini S. State of the art review: techniques to avoid poin loosening and infection in external fixation. J Orthopedic Trauma 2002; 16(3): 189-95.