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Technical note

Measuring temperature rise during orthopaedic surgical procedures

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ABSTRACT

A reliable means for measuring temperatures generated during surgical procedures is needed to recommend best practices for inserting fixation devices and minimizing the risk of osteonecrosis. Twenty four screw tests for three surgical procedures were conducted using the four thermocouples in the bone and one thermocouple in the screw. The maximum temperature rise recorded from the thermocouple in the screw (92.7 ± 8.9 °C, 158.7 ± 20.9 °C, 204.4 ± 35.2 °C) was consistently higher than the average temperature rise recorded in the bone (31.8 ± 9.3 °C, 44.9 ± 12.4 °C, 77.3 ± 12.7 °C). The same overall trend between the temperatures that resulted from three screw insertion procedures was recorded with significant statistical analyses using either the thermocouple in the screw or the average of several in-bone thermocouples. Placing a single thermocouple in the bone was determined to have limitations in accurately comparing temperatures from different external fixation screw insertion procedures. Using the preferred measurement techniques, a standard screw with a predrilled hole was found to have the lowest maximum temperatures for the shortest duration compared to the other two insertion procedures. Future studies evaluating bone temperature increase need to use reliable temperature measurements for recommending best practices to surgeons.

1. Introduction

Currently, orthopaedic fixation devices are used in both internal and external applications to stabilize bone fractures in the spine, extremities, pelvis, and skull. Ideal strategies for surgical procedures focus on maximizing the success of the fixation device to the bone while also minimizing surgery times. Success of the surgery is dependent on the device holding a secure position for a long duration [1–3]. If the insertion procedures create high bone temperatures, osteonecrosis can occur at the implantation site which can cause loosening of the screws and ultimate failure of the surgical fixation [4,5]. A reliable means for measuring temperatures generated during surgical procedures is needed to recommend best practices for minimizing the risk of osteonecrosis.

Prior researchers have commonly used thermal imaging, infrared thermometers, surface thermocouples, or thermocouples imbedded in the bone near the insertion site to measure temperature patterns and closely approximate the maximum temperature of the bone during a procedure [1,3,6–13]. Each of these techniques has limitations in determining the maximum temperature of the bone. Thermal imaging systems require data regarding the surfaces in the image as well as the surrounding environment [12]. In addition to needing these criteria and controlling them to be consistent, an additional temperature measurement device should be used for calibration of the images. Although researchers have used thermal imaging systems to understand thermal distributions in bones, there are large limitations in allowable test configurations as well as a lack of information regarding temperatures within the bone cortex [1,12]. Infrared thermometers and surface thermocouples do not directly measure the temperatures in the cortex but are used in conjunction with modeling to approximate the values [6].

The most common technique in the literature for measuring bone temperatures has been placing a thermocouple near the insertion site in the bone. Weaknesses with measuring temperatures from a procedure with a thermocouple in the bone exist in accurately positioning the thermocouple a standard distance from the source and ensuring sufficient contact of the thermocouple with the bone [2,6,8]. Even with the use of machined templates to place a thermocouple a set distance from a source, temperatures measured a distance away from the source vary because bone geometry and thermal properties are dependent on the specimen. Vertical depth into the bone also varied among tests. Moreover, the maximum temperature of the bone is not recorded because the thermocouples are typically 0.5 mm or further away from the bone interface with the device.

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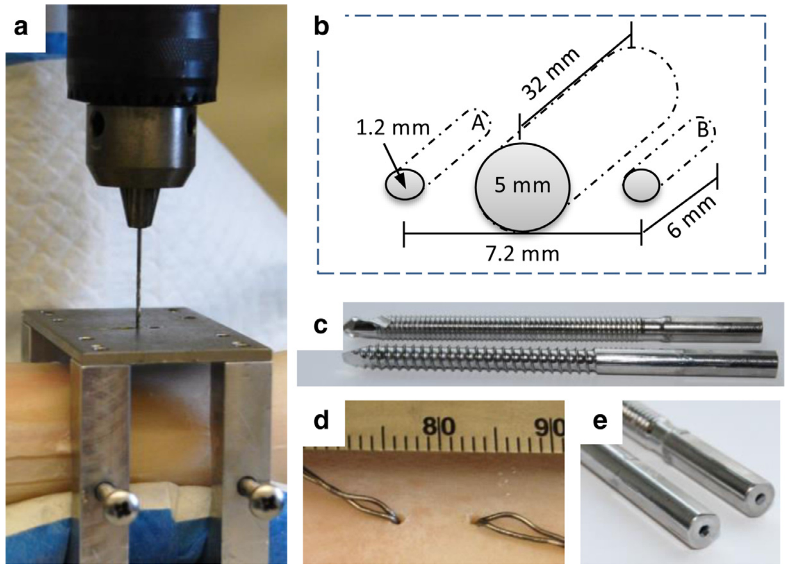

Fig. 1. (a) A custom test fixture with a machined template was used on a drill press for the thermocouple holes in the bone. (b) The spacing of the thermocouple holes placed them 0.5 mm from the outer edge of the center screw hole. (c) Standard Schanz screws and self-drilling tip Schanz screws were cut down in length for placement of a thermocouple inside each screw. (d) Two thermocouples were placed in each hole inside the bone. (e) One thermocouple was placed inside each screw for testing.

The current study used four in-bone thermocouples as well as a thermocouple in the surgical screw to assess performance of two modern and common types of external bone fixation screws. Temperatures in the device and bone were measured and compared for three surgical procedures. By evaluating the temperature measurement techniques, the best temperature measurement method can be used in future work to assess surgical procedures and recommend best practices for orthopaedic surgeons.

2. Materials and methods

Testing for screw procedures used mid-diaphysis bovine femora. Specimens were collected from the local slaughterhouse from cattle processed for the food industry. Before testing, each bone was thawed at room temperature (approximately 22 °C) for 24 h immersed in a saline solution. Four bovine femurs were used in this testing with cortical thicknesses at the test locations averaging 10.7 ± 1.8 mm.

A custom fixture was designed to hold the bone securely and provide a high tolerance for positioning the thermocouples in the bone. Holes for the insertion of the thermocouples into the bones were drilled 0.5 mm away from the outer edge of the screw insertion diameter and 180° apart from one another along the long axis of the bone (Fig. 1). The holes in the bone which housed the thermocouples were drilled with a 3/64 inch bit (1.2 mm) to a depth of 6 mm using a drill press at 980 rpm. For all tests, two sheathed 0.5 mm diameter type K thermocouples (Omega KMQSS-020U-6) were inserted completely into each hole such that the temperature was measured 6 mm from the surface of the bone. Using two thermocouples in each hole allowed for redundancy in the measurements. Bone temperatures were recorded from these thermocouples using an NI 9213 in a NI cDAQ 9188 (National Instruments Corporation, Austin, TX) at a 33 Hz sampling rate.

Twenty four screw tests were conducted using the four thermocouples in the bone and one thermocouple in the screw. In order to place the thermocouple near the drilling tip of the screw, Synthes® standard and Seldrill stainless steel 5.0 mm diameter screws were cut down to 8.4 cm in length (Fig. 1). After cutting the screw, a 1.6 mm hole was drilled down the center of the screw to a depth of 7.3 cm. A thermocouple (Omega 5SRTC-TT-K-30-36) was placed inside the hole in the center screw that stopped at the tip of the screw where the threads ended. Data for the screw thermocouple was recorded at 1 Hz using an Omega USB Data logger (Model OM-EL-USB-TC). A custom apparatus was designed to allow the screw insertion forces to be recorded using an Interface load cell (Model 2420BLX-100) while the screw was inserted using a hand drill (Dewalt DCD920KX 14.4 V ½ inch Drill) (Fig. 2).

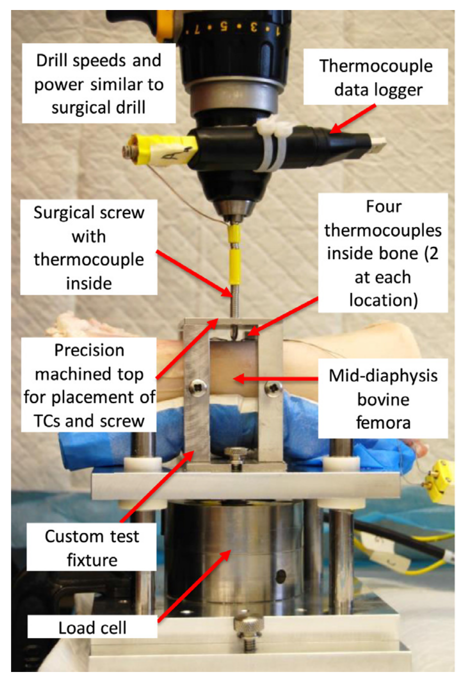

Fig. 2. A custom fixture was used for recording temperatures while inserting external fixation screws.

Eight tests were conducted with Synthes® standard screws and eight tests were conducted with Synthes® Seldrill screws. Prior to testing for these sixteen tests, a 3.5 mm diameter hole was predrilled into the bone through the near cortex as is typical in surgery. Unlike surgery, a drill press was used for the predrilled hole. However, the speed used of 570 rpm was similar to hand drills available in surgery. Eight tests were conducted with Synthes® Seldrill screws with no predrilled hole. For each test, the screw was inserted straight into the bone until the tip passed