Modern Drilling and the Impact of Plunge Distance, Biomechanical, and Thermal Properties Using Cadaveric Models

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INTRODUCTION

Drills are an essential tool in orthopaedic surgery. Pins and wires are placed in bones as temporary or permanent fixation devices, helping to assist in the maintenance of fracture reduction. Compared to other orthopaedic instruments, drill systems and pin designs have relatively lagged behind, in terms of innovation, redesign, and function. Standard drilling technique is first learned and improved throughout orthopedic residency training. Residents are taught to stop advancing after penetration of the far cortex, without plunging and damaging vital structures on the opposite side. There is an assumption this skill is one that can be learned and perfected with increased repetitions, with senior surgeons having a more precise "feel" of far cortex penetration compared to new residents[1,2].

OBJECTIVES

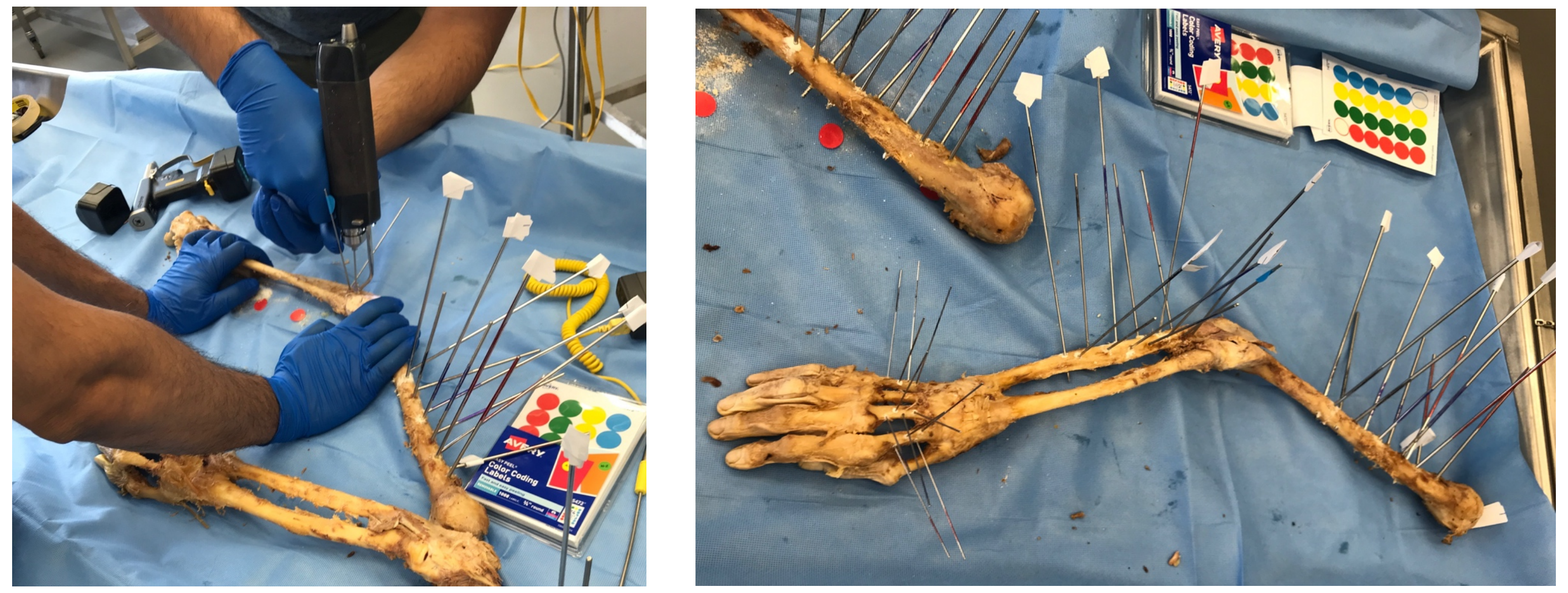
- To compare the novel McGinley Intellisense drill system with a standard Stryker driver in terms of distance of far cortex penetration. The McGinley Intellisense Drill is designed to sense cortical penetration and automatically stop when a second cortex is penetrated[3].
- To evaluate variability between drilling performance of an orthopedic hand attending, trauma surgeon, and a first-year orthopedic resident. Additional engineering data was obtained based on tensile testing and thermal analysis.

METHODS

Cadaveric study utilizing two specimens disarticulated at the shoulder. A hand surgeon, orthopaedic trauma surgeon, and a first-year orthopedic resident performed the drilling portion of the experiment. Two different drill systems were utilized, a standard Stryker and the McGinley Intellisense drills. The humerus, ulna, and first, third, and fifth metacarpal were selected for drilling. Each participant drilled two pins with each drill in the three different bones for a total of 36 trials per cadaver. The objective was to drill each pin bicortical, while minimizing the amount of penetration past the far cortex. Computed tomography scans and computer imaging software were used to calculate the distance of far cortical penetration.

Specimens were then transported to the Temple University engineering laboratory, where tensile and thermal analysis were performed. For the tensile testing, a Tinius Olsen H5TK Benchtop tester was used to calculate maximum load for pin removal in both cadaveric specimens. Tinius Olsen Navigator software was used to generate plots of force vs displacement.

For the thermal analysis, a SawBones model was created to mimic the mechanical properties of human bone. A total of 6 pins (1.1 mm, 2.0 mm, and 3.2 mm) were tested for the Intellisense and control systems. Controlling for speed and feed rate, thermal data was collected at four different time points, 1) after initial penetration of near cortex, 2) while exiting near cortex, 3) entering far cortex, and 4) after penetration of far cortex.



Figures 1 and 2: Demonstrating the plunge portion of the experiment comparing both Intellisense drilling system versus control drill. Two cadaveric samples were used with participants including one hand surgeon, one orthopedic trauma surgeon, and one first-year orthopedic resident.

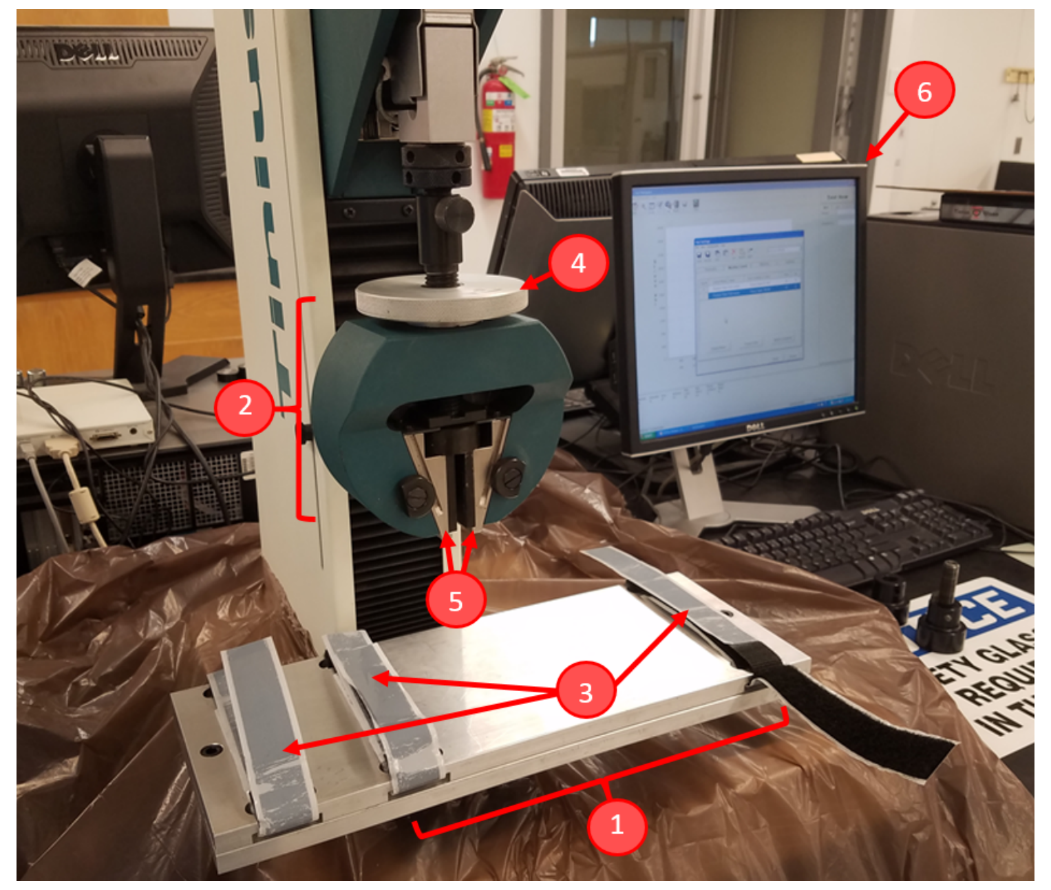
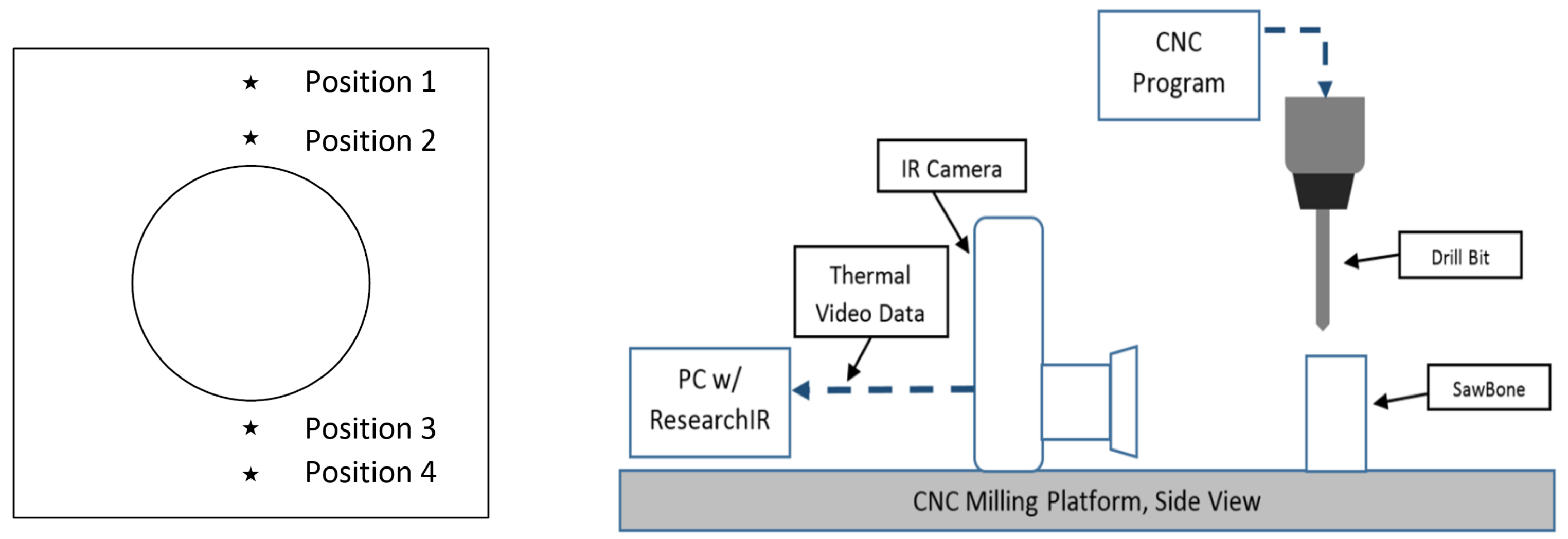


Figure 3: Testing set-up for evaluation of pin pull out strength: 1) Testing Platform, 2) Clamp Head, 3) Velcro Straps, 4) Clamp Dial, 5) Clamps, and 6) PC with Tinius Olsen Navigator program



Figures 5 and 6: Diagram of SawBones model demonstrating four positions where infrared camera recorded temperature of bone. Room temperature was approximately 25°C

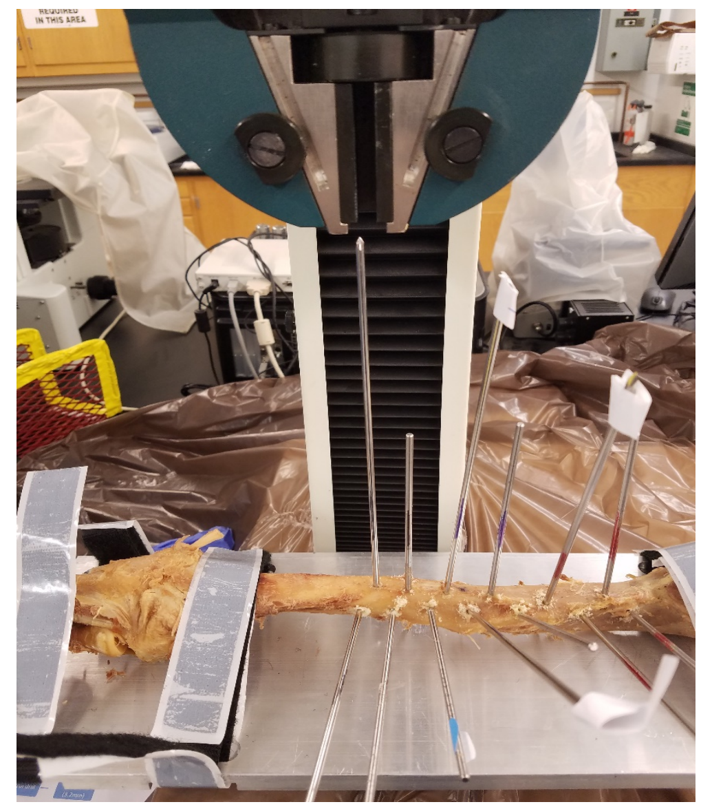


Figure 4: Demonstration of testing pull out strength of the pins

RESULTS

The mean plunge distance (interquartile range) for the control (Stryker) drilling was 5.9 mm (3.8-7.2 mm) compared to 2.8 mm (0.0-3.6 mm) for the Intellisense system, which was statistically significant ($p < 0.0001$). There was no statistical difference based on experience level ($p=0.3635$), cadaveric specimen ($p=0.9488$), or bone type ($p=0.3551$).

Tensile testing results indicated the 2.0 mm and 3.2 mm IntelliSense pins required a lower maximum load for pin removal when compared to the control pins. The load required for removal of the 2.0 mm Intellisense pins was 46.6% that of the control 2.0 mm pins. The 3.2 mm Intellisense pins required 19.2% the load of a control pin for removal. Conversely, the 1.1 mm IntelliSense pins required similar maximum loads compared to the control pins, 23.22 lb-f and 17.86 lb-f, respectively.

Thermal testing resulted in a 13.58%, 17.11%, and 10.83% temperature reduction when comparing Intellisense pins to the control group for pin diameters of 3.2 mm, 2.0 mm, and 1.1 mm, respectively.

Classification Variable	*N*	*Mean*	*StdDev*	*StdErr*	*Min*	*Q1*	*Median*	*Q3*	*Max*
Plunge Distance by Pin Type									
Generic	36	5.9	3.2	0.5	0.0	3.8	5.6	7.2	13.5
Intellisense	39	2.8	10.0	1.6	-10.2	0.0	0.0	3.6	41.9
Plunge Distance by Pin Type and Sex									
Generic and Female	18	5.4	3.0	0.7	0.0	3.6	5.1	6.7	13.2
Generic and Male	18	6.4	3.4	0.8	2.1	4.0	6.0	7.6	13.5
Intellisense and Female	19	1.7	3.5	0.8	-5.7	0.0	0.0	4.3	9.5
Intellisense and Male	20	3.8	13.7	3.1	-10.2	-1.5	0.0	2.4	41.9
Plunge Distance by Pin Type and Experience									
Generic and H	12	6.0	3.3	0.9	1.4	4.1	5.2	7.5	12.7
Generic and T	12	5.8	3.2	0.9	2.1	3.8	5.4	7.5	13.5
Generic and R	12	5.9	3.4	1.0	0.0	3.6	6.4	6.9	13.2
Intellisense and H	13	-0.5	3.9	1.1	-10.2	0.0	0.0	0.7	4.3
Intellisense and T	12	3.2	12.3	3.6	-7.9	0.0	0.0	3.2	40.6
Intellisense and R	14	5.5	11.5	3.1	-3.8	0.0	2.0	5.8	41.9
Plunge Distance by Pin Type and Bone									
Generic and Humerus	12	6.8	2.0	0.6	4.2	5.8	6.6	7.3	11.1
Generic and Metacarpal	12	3.2	1.0	0.3	1.4	2.5	3.3	4.1	4.5
Generic and Ulna	12	7.7	3.9	1.1	0.0	5.5	7.2	10.8	13.5
Intellisense and Humerus	13	-0.2	6.2	1.7	-10.2	-3.8	0.0	0.0	13.6
Intellisense and Metacarpal	13	2.7	3.1	0.8	-3.0	0.7	2.7	4.2	9.5
Intellisense and Ulna	13	5.9	15.8	4.4	-6.0	0.0	0.0	0.0	41.9

Table 1: Summary data of plunge distance by selected two-way variable combinations. H: Hand surgeon, T: Trauma surgeon: R: Resident

Classification Variable	*N*	*Mean*	*StdDev*	*StdErr*	*Min*	*Q1*	*Median*	*Q3*	*Max*
Max Load by Pin Type									
Generic	36	39.4	26.3	4.4	6.1	19.4	28.5	58.2	113.2
Intellisense	39	16.4	15.3	2.5	0.0	3.8	14.0	23.3	56.0
Max Load by Bone									
Humerus	25	39.8	32.6	6.5	0.0	8.8	32.1	67.2	113.2
Metacarpal	25	19.9	8.3	1.7	0.0	16.5	18.8	24.7	36.2
Ulna	25	22.6	20.4	4.1	0.0	3.8	20.1	44.2	58.2
Max Load by Pin Type and Bone									
Generic and Humerus	12	69.6	18.2	5.3	43.9	56.3	69.3	77.1	113.2
Generic and Metacarpal	12	18.4	6.9	2.0	7.8	12.3	17.9	25.1	29.3
Generic and Ulna	12	30.2	15.8	4.6	6.1	20.1	27.2	44.6	58.2
Intellisense and Humerus	13	12.3	10.5	2.9	0.0	6.1	8.8	18.3	32.1
Intellisense and Metacarpal	13	21.3	9.4	2.6	0.0	18.1	19.8	24.1	36.2
Intellisense and Ulna	13	15.6	22.3	6.2	0.0	1.5	3.8	15.5	56.0

Table 2: Summary data of max load by pin type and bone.

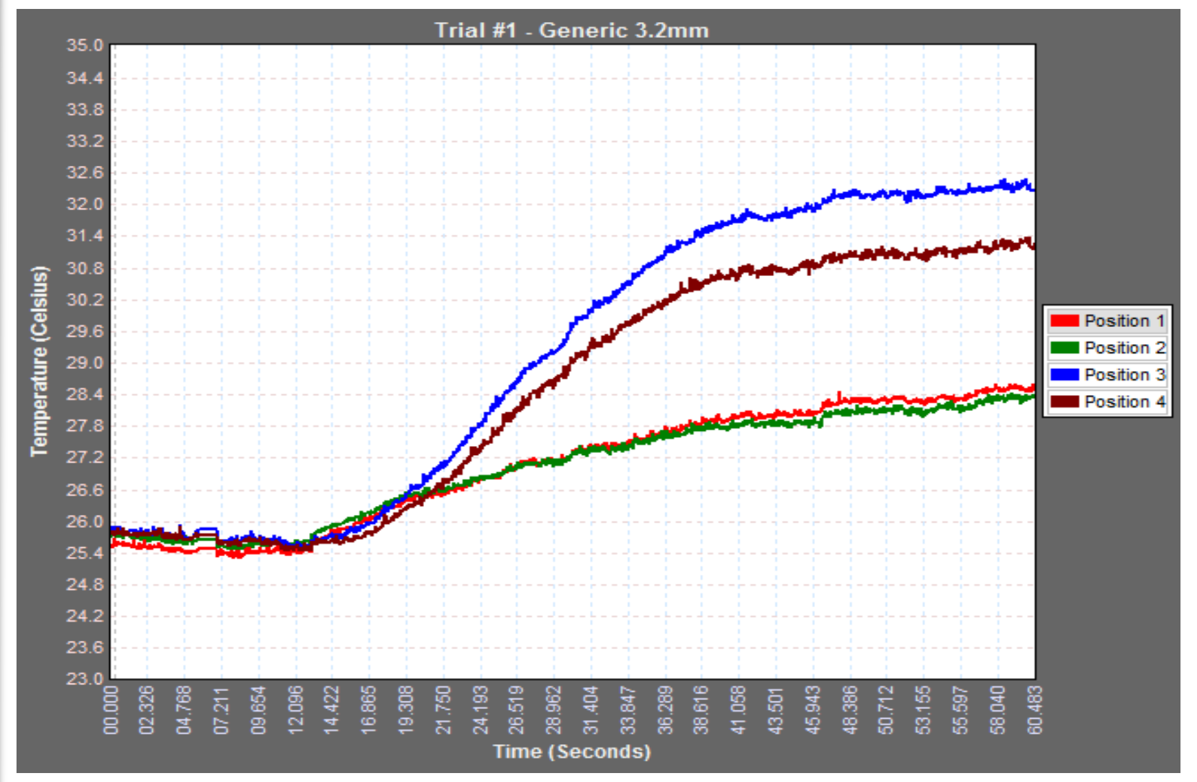


Figure 7: Plot of maximum temperature (°C) with Generic 3.2 mm pin with peak at Position 3 of 32.4°C

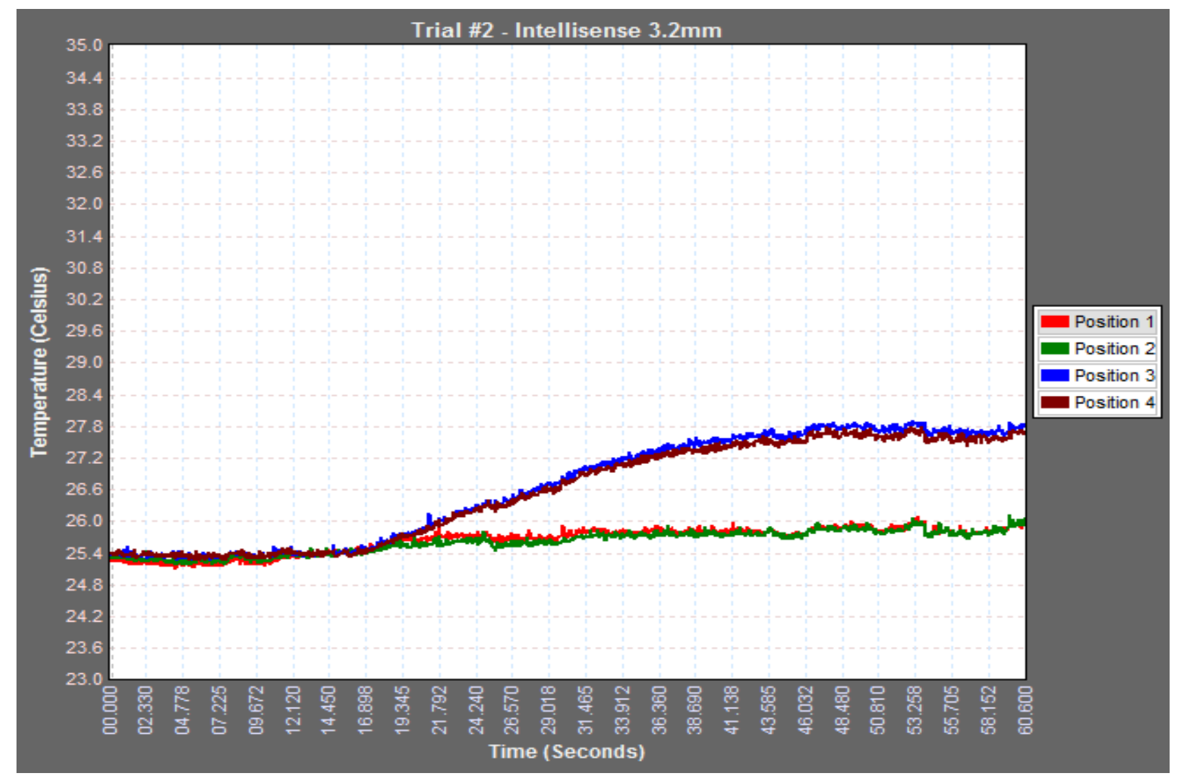


Figure 8: Plot of maximum temperature (°C) with Intellisense 3.2 mm pin with peak at Position 3 of 28.0°C

Pin Diameter (mm)	Maximum Temperature (°C)		Percent Temperature Reduction
	Generic Pin	Intellisense Pin	
3.2	32.4	28.0	13.58%
2.0	40.9	33.9	17.11%
1.1	35.1	31.3	10.83%

Table 3: Peak temperatures for pin diameters 3.2, 2.0, and 1.1 mm for the Generic and Intellisense pins

CONCLUSION

While the Intellisense drilling system minimized plunge distance past the far cortex, it did not perform as well on the biomechanical testing in terms of overall tensile strength. Thermal analysis demonstrated reduced heat generation of the Intellisense pins for each diameter compared to control pins. This thermal reduction may lower peak temperatures during drilling especially with successive pin placement, reducing the risk of thermal osteonecrosis.

REFERENCES

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