INTERNATIONAL JOURNAL of SPINE SURGERY

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Int J Spine Surg published online 20 April 2023
http://ijssurgery.com/content/early/2023/04/20/8471

The International Journal of Spine Surgery
2397 Waterbury Circle, Suite 1,
Aurora, IL 60504, Phone: +1-630-375-1432

International Journal of Spine Surgery Publish Ahead of Print, published on April 20, 2023 as doi:10.14444/8471

International Journal of Spine Surgery, Vol. 00, No. 0, 2023, pp. 1–5
https://doi.org/10.14444/8471

Thermal Generation in Spinal Surgery: Does Rate of Irrigation Matter During Anterior Cervical Discectomy?

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ABSTRACT

Background: High-speed rotational burring is considered the mainstay of modern spinal decompression surgery. However, high-energy burrs generate significant heat due to the friction between the bone and the rotating burr. This study determines the effects of automated irrigation rate on burr tip temperatures either with a serrated steel burr or diamond-coated burr during anterior cervical discectomy and fusion (ACDF).

Methods: This is an observational study of the routine practice of a single surgeon for 20 patients aged 18 years or older undergoing elective single- or multilevel ACDF. Various continuous irrigation rates of 0, 0.5, 1.0, or 2.0 cc/min were used. Forward-looking infrared thermography was used to measure the burr tip temperatures. The Midas Rex Legend EHS (Medtronic, PLC, Minneapolis, MN) stylus high-speed surgical drill was used with 3-mm burrs (diamond-coated and carbide-serrated steel) paired to the Medtronic Integrated Power Console set at 60,000 rpm.

Results: The 0.5-cc/min irrigation rate kept the maximum burr temperatures below 45°C ($P < .001$). With no irrigation (0 cc/min), the steel burrs reached a maximum of 141°C, and the diamond-coated burrs reached 177°C, which was the only significant difference related to the burr materials ($P = 0.0354$). With irrigation rates of 0.5 cc/min and above, the maximum recorded temperature for steel burrs was 40.6°C, and the maximum temperature for diamond-coated burrs was 38.9°C. Irrigation rates greater than 0.5 cc/min yielded little additional benefit.

Conclusion: This study highlights the importance of adequate irrigation during high-speed burr drilling. Continuous irrigation is recommended even as low as 0.5 cc/min. It is good operative practice to reduce the risk of heat transmission to surrounding tissues, especially considering the proximity of cervical spinal nerve roots during uncoforaminal decompression.

Level of Evidence: 3.

Cervical Spine

Keywords: thermal, burr, irrigation, rate, spine

INTRODUCTION

High-speed rotational burring is considered the mainstay of modern spinal decompression surgery. However, high-energy burrs generate significant heat due to the friction between the bone and the rotating burr. Heat generation poses 2 threats: thermal osteonecrosis and thermal injury to the surrounding neural structures. C5 nerve root palsy is the most common complication following cervical decompression, occurring in 8% of procedures via the anterior approach.[1] Exposure to ≥47°C for 60 seconds can lead to irreversible bone death,[2] while prolonged exposure at 45°C causes nerve damage.[3]

Irrigation minimizes this risk through operator-dependent manual irrigation or drill-attached continuous irrigation systems. Nevertheless, the drawback of excess quantities of irrigation is the obscuration and soaking of the operative field, along with frequent interruption for suctioning.[4,5]

This study aims to determine the significance of irrigation rate and its effect on burr tip temperatures during anterior cervical discectomy and fusion (ACDF). The study also assesses the difference in temperatures between steel and diamond-coated burrs. We hypothesized that higher irrigation rates would yield lower burr tip temperatures.

METHODS

This is an observational study of the routine practice of a single surgeon for 20 patients aged 18 years or older undergoing elective single- or multilevel ACDF. Various continuous irrigation rates of 0, 0.5, 1.0, or 2.0 cc/min were used for each patient. Where 0 cc/min of automated irrigation was used, manual irrigation with saline drawn up in a syringe in between burring intervals was performed. The Midas Rex Legend EHS stylus high-speed surgical drill was used with 3-mm burrs (diamond-coated and carbide-serrated steel) paired to the Medtronic Integrated Power Console set at 60,000

Figure 1. Diagram of the study setup.

rpm. Forward-looking infrared thermography was used in this study for temperature measurements. We used the Hikvision M30 handheld thermal camera (HikMicro, Hangzhou, China) with a resolution of 384 × 288 (110,592 pixels), a thermal range of −20°C to 550°C with an accuracy of ±2%.

Initial measurements included the temperature of irrigation saline used and the baseline temperature of the burr tips prior to high-speed drilling. Other variables were also recorded, including operating theater temperature and humidity.

The steel burr was used for resection of anterior cervical osteophytes, end plate preparation, and discectomy, while the diamond-coated burr was used for uncoforaminal microscopic decompression. After a period of burr usage at each decompression level, the burr tip temperatures were measured via infrared thermography from 50 cm. The burr was allowed to cool adequately prior to further intermittent drilling (Figures 1 and 2).

Statistical analysis was performed using GraphPad Prism 9, Version 9.2.0 (GraphPad Software, Inc., San Diego, CA). We used the Kruskal-Wallis 1-way analysis of variance with 95% confidence intervals to compare the mean temperatures of the steel burr at each irrigation rate. A comparison between irrigation rates was performed using the Mann-Whitney U test for the steel and diamond groups. Differences between groups were significant at $P < 0.05$.

RESULTS

The mean irrigation saline temperature was 20.7°C, while the mean baseline burr tip temperature was

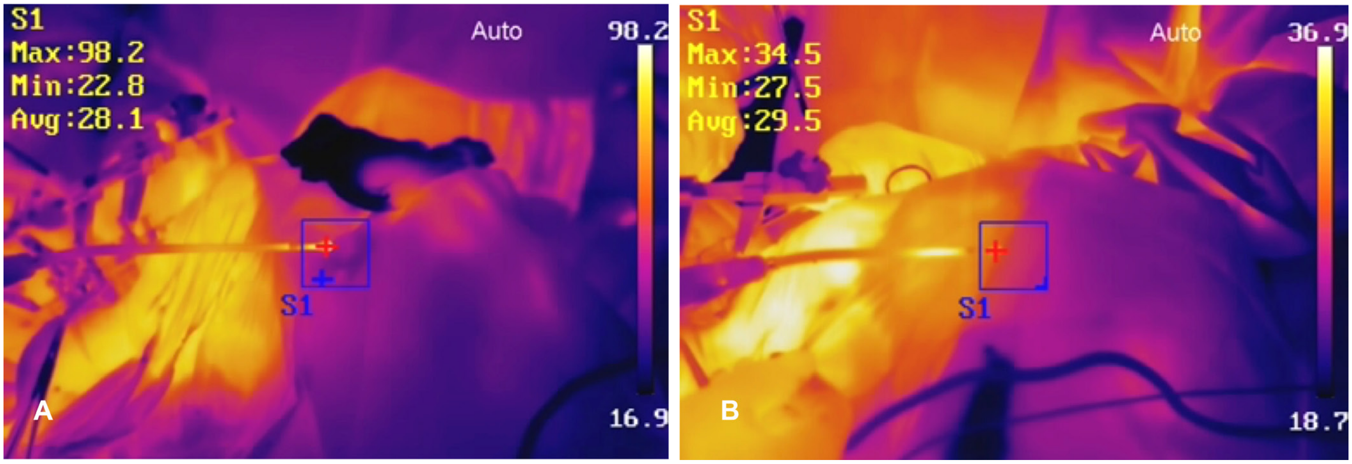

Figure 2. Thermographic images (A, B) of burr tips. The red cross (A) overlies the center of the burr tip, which also corresponds to the maximum temperature reading of 98.2°C. IPC, Integrated Power Console.

19.8°C. The operating theater average temperature was 18°C, and the average relative humidity was 56.8%.

Burr Tip Temperature With Different Rates of Irrigation

As little as 0.5 cc/min of irrigation keeps the maximum burr temperatures below 45°C. We found a statistically significant difference between the mean temperature of burr tips and different rates of irrigation ($P < 0.001$; Kruskal-Wallis test). At 0 cc/min, the steel burr mean temperature was 72.8°C (141°C maximum). Diamond-coated burrs yielded a similar result with a mean temperature of 90.7°C (177°C maximum). With irrigation rates of 0.5 cc/min and above, the maximum recorded temperature for steel burrs was 40.6°C, and the maximum temperature for diamond burrs was 38.9°C. The hypothesis does not hold true for irrigation rates higher than 0.5 cc/min (Tables 1 and 2, Figure 3).

Statistical significance was demonstrated in steel and diamond burr temperatures when irrigation rates of 0 and 0.5 cc/min are compared ($P < 0.001$; Mann-Whitney U test). However, the burr tip temperatures did not vary significantly when the 0.5, 1.0, and 2 cc/min groups were sequentially compared.

Comparison of Steel and Diamond-Coated Burr Temperatures

Only the 0 cc/min rate demonstrated a significant difference ($P = 0.035$; Mann-Whitney U test) between burr materials, with an average difference of 17.9°C. At 0.5, 1.0, and 2.0 cc/min rates of irrigation, the temperature differences between the steel and diamond burrs were not statistically significant (Table 3).

DISCUSSION

The most used burrs are cutting serrated carbide steel burrs and diamond-coated burrs. The latter is preferred for delicate decompression during uncoforaminal decompression because they will not snag soft tissue. This minimizes the risk of injury to the underlying dura, spinal cord, and nerve roots.[6]

C5 palsy has a distinctive time delay of up to 3 days until its clinical manifestation. The proposed

Table 1. Effect of different irrigation rates on steel burr tip temperatures.

	Steel Burr Tip Temperature, °C		
Irrigation Rate	**Mean ± SD**	**Range**	***P* Value**
0 cc/min	72.8 ± 24.9	34–141	
0.5 cc/min	32.4 ± 5.3	23.3–40.6	<0.0001[a]
1 cc/min	30.5 ± 4.8	19.3–36.8	
2 cc/min	32.8 ± 2.8	28–37.5	
Comparison of Temperatures			
0 vs 0.5 cc/min			<0.0001[b]
0.5 vs 1 cc/min			0.203[b]
1 vs 2 cc/min			0.174[b]

[a]Kruskal-Wallis test.
[b]Mann-Whitney U test.

Table 2. Effect of different irrigation rates on diamond burr tip temperatures.

	Diamond Burr Tip Temperature, °C		
Irrigation Rate	**Mean ± SD**	**Range**	***P* Value**
0 cc/min	90.7 ± 33.0	51–177	
0.5 cc/min	30.9 ± 4.8	24.9–38.9	<0.0001[a]
1 cc/min	31.5 ± 2.9	28.8–37.4	
2 cc/min	32.1 ± 2.0	27.5–34.3	
Comparison of Temperatures			
0 vs 0.5 cc/min			<0.0001[b]
0.5 vs 1 cc/min			0.682[b]
1 vs 2 cc/min			0.268[b]

[a]Kruskal-Wallis test.
[b]Mann-Whitney U test.

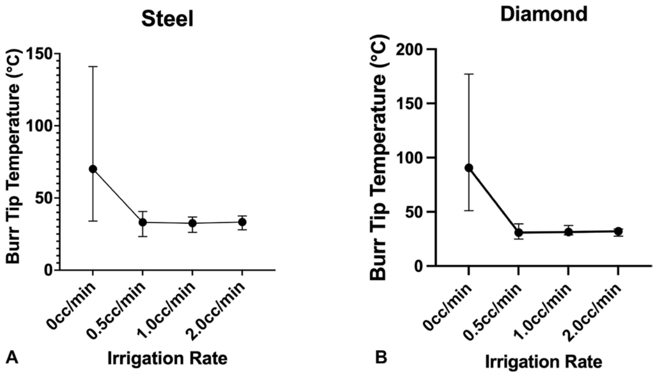

Figure 3. (A) Steel and (B) diamond burr tip temperatures against irrigation rate.

mechanisms of C5 palsy include perioperative nerve root injury, the "tethering theory" (whereby nerve root traction occurs secondary to the posterior shift of the spinal cord), ischemia, and reperfusion injury following decompression.[7] Recent studies have proposed that the frictional heat generated from high-speed drills causes histological nerve root injury.[1,7,8]

Hoogeveen et al reported that ultrastructural changes in the rat sciatic nerve, such as immediate edema, blood vessel occlusion, and severe endothelial cell injury, were observed after exposure at 45°C. They also noted ischemia and accumulation of cell organelles, concluding that hyperthermia is linked to direct endothelial and myelin sheath injury, while axon degeneration is a likely consequence of ischemia.[9,10] Xu and Pollock reported that the delayed ischemic lesions were secondary to extensive thromboses of the vasa nervorum.[11]

C5 palsy due to thermal injury is not easy to prove in vivo. Takenaka et al used muscle strength to investigate the effect of chilled saline irrigation on the incidence of C5 palsy, of which at least a 2-fold decrease of deltoid weakness was observed in chilled vs room temperature saline.[8] This highlights the importance of adequate irrigation during cervical decompression surgery to minimize the incidence of upper limb palsy.

Our focus was on the potential thermal injury to the nerve roots, given the proximity of the site of burring to the cervical nerve roots. Delivery of a coolant solution eliminates bone chips and lubricates the drills, both of which reduce friction-generated heat. To the best of our knowledge, this is the first study investigating the significance of the rate of small-volume automated irrigation in anterior cervical decompression.

Table 3. Comparison of steel vs diamond burrs temperatures at each irrigation rate.

Comparison of Temperatures by Irrigation Rate	*P* Value[a]
0 cc/min	0.0354
0.5 cc/min	0.407
1 cc/min	0.698
2 cc/min	0.579

[a]Mann-Whitney U test.

At 0 cc/min, the steel burr's mean temperature was 72.8°C, with a maximum of 141°C. The diamond burrs, on the other hand, were hotter with a mean temperature of 90.66°C and a maximum of 177°C. Hosono et al found similar results in 2009.[1]

Any amount of irrigation at a rate of 0.5 cc/min or more maintains the maximum burr temperatures below 45°C. There is a statistically significant difference ($P < 0.001$; Kruskal-Wallis test) at 0.5 cc/min (30 mL/h); this is a much smaller volume of irrigation than earlier studies. The exact reasons are unknown; however, the targeted delivery of irrigation and the high specific heat capacity of water are likely to contribute to the above findings.

Hosono et al concluded that water irrigation at a rate of 540 mL/h (9 cc/min) was required to reduce the bone temperature of porcine lumbar transverse processes effectively. The authors used the Stryker Total Performance System high-speed drill, which prohibits direct comparison with our results, given the differences in equipment designs. At 540 mL/h (9 cc/min), the maximum temperature with the diamond burr was 52°C, and the maximum temperature with the steel burr was 44°C.[1] High flow rates would cause significant obscuration of view, especially in the tight intervertebral spaces during an ACDF, as compared with a posterior approach lumbar spine laminectomy. Our experience with irrigation rates of 0.5 cc/min and above recorded maximum burr temperatures of 40.6°C in steel burrs and 38.9°C in diamond burrs. As such, the hypothesis that an increased irrigation rate leads to lower burr temperatures does not hold true for irrigation rates at 0.5 cc/min and above.

Matthes et al also compared burr temperatures during lumbar decompression using automatic or manual irrigation. They demonstrated that the average burr temperature was 82°C (maximum 119.5°C) for high-speed drills with 1200 mL/h (20 cc/min) automatic irrigation and 100°C (maximum 148.2°C) for manual irrigation at an average rate of 1665 mL/h (27.8 cc/min) ($P < 0.001$), concluding that automated irrigation was superior to manual irrigation.[2] Again, a much larger amount of irrigation was used compared with the 0.5 cc/min (30 mL/h) used in our study.

There are several limitations to this study. First, a larger sample size would make this a more powerful study. However, the study was conducted at an elective spinal orthopedic theater, availability was severely affected by coronavirus disease 2019, and the data collection time would have become protracted. Second, we used infrared thermography as an indirect measure of temperature, where certain values must be extrapolated[12] and can be dependent on working conditions, such as ambient temperature and humidity.[13] However, its noninvasive, noncontact properties of temperature measurement make it safe and practical, which have been used in several similar studies.[1,2,4] Due to the limited intervertebral space and the depth at which uncoforaminal decompression is performed, the burr tip temperatures were measured as the closest representation of the friction-generated heat at the bone-burr interface. It also must be noted that our findings may not apply to all high-speed drill systems. Lastly, measuring the burr tip with infrared thermography introduced a time interval of approximately 5 seconds. A real-time measurement would increase the accuracy of this study because some heat will have dissipated between the end of friction and the start of measurement.

CONCLUSION

High-speed drilling generates a significant amount of heat. This study highlights the importance of adequate irrigation during high-speed burr drilling. We have found that continuous irrigation as low as 0.5 cc/min maintains the maximum burr temperatures below 45°C. It is good operative practice to reduce the risk of heat transmission to surrounding tissues, especially considering the proximity of cervical spinal nerve roots during uncoforaminal decompression.

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Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests: The authors report no conflicts of interest in this work.

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