RESEARCH

Potential risk of thermal damage to cervical nerve roots by a high-speed drill

N. Hosono, T. Miwa, Y. Mukai, S. Takenaka, T. Makino, T. Fuji

From Osaka Kosei-nenkin Hospital, Fukushima, Japan

Using the transverse processes of fresh porcine lumbar spines as an experimental model we evaluated the heat generated by a rotating burr of a high-speed drill in cutting the bone. The temperature at the drilled site reached 174°C with a diamond burr and 77°C with a steel burr. With water irrigation at a flow rate of 540 ml/hr an effective reduction in the temperature was achieved whereas irrigation with water at 180 ml/hr was much less effective. There was a significant negative correlation between the thickness of the residual bone and the temperature measured at its undersurface adjacent to the drilling site (p < 0.001).

Our data suggest that tissues neighbouring the drilled bone, especially nerve roots, can be damaged by the heat generated from the tip of a high-speed drill. Nerve-root palsy, one of the most common complications of cervical spinal surgery, may be caused by thermal damage to nerve roots arising in this manner.

A high-speed drill has been considered to be essential for surgery on the spine. It can be used to make precise bone cuts using various types of burr. Although the drill is believed to be safe, the effect of the heat of friction generated between the rotating burr and bone is not fully understood. There is some debate as to how much heat is generated and to what temperature the bone rises. The cooling effect of irrigating with water while drilling is also unknown. It has been observed that thermal damage to neural tissues close to the drilled bone may occur. A palsy of the C5 root is one of the most common complications of cervical spinal surgery through the anterior or posterior approach and has been regarded as an inherent risk and almost inevitable event, whether it involves a lesion of the nerve root or spinal cord. We suspect that C5 palsy may result from thermal damage to the nerve roots caused by the heat generated by the friction of a high-speed drill against bone. We have therefore undertaken an investigation to determine the temperature of drilled bone and have reviewed the literature on C5 palsy and its possible relationship to thermal injury.

Materials and Methods

We used fresh porcine lumbar spines as the experimental model. The specimens were secured to the table with the transverse processes, each of which was 3 mm to 7 mm thick, orientated vertically. Three drilling regions, each 15 mm long, were identified on each transverse process. A Stryker Total Performance System high-speed drill (Stryker Instruments, Kalamazoo, Michigan), set at 75 000 rpm, was mounted with a 5 mm steel or diamond burr. In order to measure the temperature of the undersurface of the drilled bone, an infrared radiation thermometer (TH3101MR; NEC Avio Technologies Co, Tokyo, Japan) was placed 50 cm from the specimen (Fig. 1). The thermometer could detect a change in temperature of 0.08°C which was recorded on a thermograph.

Experiment 1. Surgeon A, the senior author (NH) drilled various sites on the transverse processes until the burr perforated the bone as follows:

1A, a steel-tipped burr was used without irrigation at six sites;
2A, a diamond-tipped burr was used without irrigation at six sites;
3A, a steel-tipped burr irrigated by water at a rate of flow of 540 ml/hr was used at three sites;
4A, a diamond-tipped burr irrigated by water at a rate of flow of 540 ml/hr was used at three sites.
Surgeon B (MT) with two years of experience in spinal surgery undertook further drilling:

1B, a diamond-tipped drill without irrigation at three sites;
2B, a diamond-tipped drill with irrigation by water at a rate of 540 ml/hr at three sites.

For each drilling thermal data were recorded every ten seconds throughout the procedure.

**Experiment II.** In order to investigate the heat transmission through bone ten regions of the specimens were drilled using a diamond-tipped burr without irrigation until the residual bone thickness was 0.5 mm to 3 mm. Thermal data were recorded just before the drilling stopped and the actual residual thickness of bone was measured by a micrometer caliper.

**Statistical analysis.** In experiment I the Wilcoxon signed-rank test was used with StatView for Windows version 5.0 (SAS Institute Inc, Cary, North Carolina). A p-value of ≤ 0.05 was considered to be statistically significant.

**Results**

**Experiment I.** The mean drilling time until perforation was 113 s (90 to 150) for 1A, 82 s (40 to 110) for 2A, 47 s (40 to 50) for 3A, 177 s (170 to 190) for 4A, 40 s (30 to 50) for 5A, 120 s (100 to 150) for 6A, 100 s (70 to 120) for 1B and 150 s (120 to 150) for 2B (Fig. 2). The mean time required for drilling with a steel-tipped burr in all three situations was 60 s (30 to 150) (1A, 3A, 5A) which was shorter than that required with a diamond-tipped burr which was 115 s (40 to 190) (2A, 4A, 6A), but the difference was not statistically significant (p = 0.146). Comparing the drilling time required using matched diamond-tipped burrs and irrigation systems surgeon A (2A, 6A) was quicker than surgeon B (1B, 2B), although the differences were not statistically significant (94 s (40 to 150) vs 125 s (70 to 190), respectively; p = 0.104).

The mean temperature of the regions measured was 23°C (21.8 to 24.2) before drilling, and the time course of the mean temperature as it increased above 30°C was plotted against time in each group (Fig. 3). The maximum temperature was 77°C for 1A, 141°C for 2A, 39°C for 3A, 174°C for 4A, 44°C for 5A, 52°C for 6A, 110°C for 1B and 94°C for 2B. The mean maximum temperature generated by a diamond burr was higher than that generated by a steel burr when comparing 1A with 2A (66°C (47 to 77) vs 114°C (79 to 141), respectively; p = 0.028). Water irrigation of 540 ml/hr effectively reduced the temperature of the bone drilled by the diamond-tipped burr, with the temperature of the bone drilled without irrigation (2A) being significantly higher than that with irrigation (6A, 2B) (114°C vs 63°C, respectively; p = 0.028).

**Experiment II.** The temperature of the under surface of the bone in each setting was significantly correlated with the residual bone thickness (Fig. 4) (Pearson’s correlation coefficient, r = -0.958, p < 0.001).

**Discussion**

Our study has shown that the temperature of the bone surface adjacent to the penetrating burr was often higher than 45°C and reached in excess of 100°C, especially when a diamond burr was used for drilling and/or insufficient water irrigation was used. Furthermore, heat transmission through bone was negatively correlated with the thickness of the residual bone.

During surgery to the cervical spine, water irrigation can be insufficient and the drilling time can be longer than that in our study. Nerve roots will therefore be at risk of damage by the heat generated by the burr on a high-speed drill penetrating the bone. We propose that a C5 nerve-root palsy or palsy of the upper limb may result from thermal damage to the nerve roots caused by a high-speed drill. The cause of
this complication has remained uncertain. Whether it originates in the nerve roots or the spinal cord, palsy of an upper limb is well known to accompany decompressive procedures for the cervical spinal cord. We believe that this results from thermal damage, and can be prevented.

Nerve palsy of an upper limb is generally not considered to result from an intra-operative incident because of the latent period between surgery and the development of neuropathy. However,Fan et al observed that impending C5 nerve-root injuries could be successfully identified in patients showing significant changes in intra-operative neurophysiological monitoring, which would suggest intra-operative damage to the nerve root. Unlike former reports, recent prospective studies have shown an earlier onset of palsy of an upper limb. In a study by Sakaura et al four of ten patients, and in another Seichi et al five of nine patients, presented with palsy on the day of surgery. De Vrind, Wondergem and Haverman noted that heating of the rat sciatic nerve to 45°C for 15 minutes induced a loss of sensory and motor function of 50%, and that increasing the temperature by 1°C resulted in a decrease of 50% in time for heating to cause the same level of damage. Functional damage was apparent 3.5 hours after heat treatment at 45°C to the sciatic nerve of rats, and complete loss of function occurred after exposure for eight hours to this temperature. Hoogeveen et al also observed a discrepancy of seven hours between hyperthermia and the onset of loss of nerve function, whereas crush injury produced immediate paralysis. Although the exact reason for such a latent period is unclear, it is possible that it results from a heat-induced angiopathy. In a study on the rat sciatic nerve, Xu and Pollock found heat-induced, delayed, ischaemic lesions within myelinated nerves because of extensive thromboses of the vasa nervorum. In human median nerves, epineurial blood vessels have been reported to suffer thrombosis due to heat injury during bone cementing.

Although a short latent period for the onset of an upper-limb palsy after surgery due to heat injury would be in keeping with the results of animal studies, we are uncertain as to whether an extended delay between surgery and the onset of palsy can be similarly explained. Other factors may also be relevant. In a study on rats, almost complete recovery of motor function was achieved 30 days after exposure to heat. Bull et al found that 30% of patients who were exposed to hyperthermia at 41.8°C had symptoms of peripheral neuropathy within 24 hours, which suggests the susceptibility of peripheral nerves to heat. The patients in their study also recovered from the peripheral neuropathy over some weeks. These findings are compatible with the benign nature of nerve palsy in the upper-limb, which generally recovers over months after surgery.

Although much has been written rationalising the occurrence of unilateral C5 nerve-root palsy, recent studies have shown the involvement of every root, including C5, C6, C7 and C8 either alone or in combination. Thermal damage would be anticipated wherever a high-speed drill approached a nerve root with an increase of the risk in proportion to the number of operated levels. There are reports that the incidence of nerve palsy increased with the number of levels treated, not only in posterior surgery such as laminoplasty, but in anterior surgery of the cervical spine. It has also been stated that drilling too laterally on the cervical spine is a risk factor for the occurrence of a palsy both in laminoplasty and anterior surgery. Given the lateral placement of the cervical nerve roots it seems reasonable that drilling more laterally would provoke a higher incidence of palsies than more medial placement of the drill. In laminotomy procedures in which drilling is confined to the lower part of the superior lamina and upper part of the inferior lamina, palsies have not occurred. In a review of the literature, we have found that nerve palsy is more often observed after
surgery for ossification of the posterior longitudinal ligament than after operations for spondylotic myelopathy.\textsuperscript{3,15,21} In ossification of the posterior longitudinal ligament the bone is generally very hard requiring prolonged drilling which would increase the period of exposure to heat.

Some surgeons believe that a cervical root palsy can be avoided by prophylactic resection of the facet to release nerve roots.\textsuperscript{22-24} Such action would, however, increase the risk of heat damage due to the intensive drilling of bone in the vicinity of the roots.

There were some limitations to our study. The experiment was an in vitro study and therefore lacked bone bleeding which may have a cooling effect. Nevertheless the critical area for thermal injury is the cortical bone adjacent to the nerves, from which less bleeding occurs than from cancellous bone. Another limitation was that the intraoperative drilling time might be longer when care has to be taken to avoid injury to the spinal cord. As a result, the temperature curve over time may be different in vivo.

The relevance of avoiding high temperatures when drilling in the region of the cervical spine has been recognised since the introduction of the high-speed drill to clinical practice.\textsuperscript{25} Our study highlights the high temperatures which can occur and the importance of adequate measures to reduce the risk of heat-related nerve injury.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References