Waterjet dissection of the vestibulocochlear nerve: an experimental study

Laboratory investigation

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Object. Waterjet dissection has been shown to protect intracerebral vessels, but no experience exists in applying this modality to the cranial nerves. To evaluate its potential, the authors examined waterjet dissection of the vestibulocochlear nerve in rats.

Methods. Lateral suboccipital craniectomy and microsurgical preparation of the vestibulocochlear nerve were performed in 42 rats. Water pressures of 2–10 bar were applied, and the effect was microscopically evaluated. Auditory brainstem responses (ABRs) were used to define nerve function compared with preoperative values and the healthy contralateral side. The final anatomical preparation documented the morphological and histological effects of waterjet pressure on the nerve.

Results. In using up to 6 bar, the cochlear nerve was preserved in all cases. Eight bar moderately damaged the nerve surface. A 10-bar jet markedly damaged or even completely dissected the nerve. Time course analysis of the ABR demonstrated complete functional nerve preservation up to 6 bar after 6 weeks in all rats. Waterjet dissection with 8 bar was associated with a 60% recovery of ABR. In the 10-bar group, no recovery was seen.

Conclusions. Microsurgical dissection of cranial nerves is possible using waterjet dissection while preserving both morphology and function. The aforementioned jet pressures are known to be effective in neurosurgical treatment of tumors. Thus, waterjet dissection may be useful in skull base surgery including dissection of cranial nerves from tumors. Further studies on this subject are encouraged. (DOI: 10.3171/2008.5.17561)

KEY WORDS • cranial nerve • hydrojet dissection • vestibular schwannoma • vestibulocochlear nerve • waterjet dissection

W A T E R J E T dissection is an approved technique established in an expanding variety of surgical disciplines. Early use of waterjet dissection has been reported in liver and kidney surgery.10,30,31,34,35,52 Subsequently, waterjet dissection was used in orthopedic procedures,8,9,16,41,48 urological and hepatic surgery,2,45,56 parotid surgery,18,47 ophthalmological surgery,6,18,19,53–55 with endovascular techniques,20 and in thoracoabdominal surgery.15,17 The first application of waterjet dissection in neurosurgery was reported by Terzis et al.51 in 1989. However, because of the high variations in the resulting cutting depth, no further studies followed this group’s. Since the mid-1990s, our group has investigated the potential of the waterjet dissection technique in neurological procedures.22,23,27,32,33 It has been documented that sparing of, and precise dissection of, brain tissue is possible when using the waterjet technique. Preserving vessels and consecutive minimization of blood loss played a decisive role in further studies.24,25 The waterjet instrument was thoroughly evaluated in various intracranial tumor indications23,29,32 and in surgery for temporal lobe epilepsy.25

Surgery of tumors within or adjacent to cranial nerves remains challenging for neurosurgeons.1,3,13,21,37–39,44,49,57 In particular, surgical treatment of vestibular schwannoma, which has a high risk of injury to the facial and vestibulocochlear nerve, represents a challenge.7,38,44 The surgical gains are complete tumor removal while preserving hearing and facial nerve function. In high-risk patients, subtotal removal is a possible option to avoid nerve deficits. In treating very large or cystic tumors there is a significant risk of injury to the facial nerve and of causing complete hearing loss.13 Advances in surgical techniques and the introduction of electrophysiological monitoring have markedly improved the rates of hearing and facial
nervous surgery has been to protect blood vessels. The first experiences with the technique's effect on nerve tissue were reported by investigators who used a nerve-sparing dissection technique on peripheral nerves. In cranial nerves, particularly in vestibular schwannoma surgery, a technique enabling more comfortable preservation of facial or vestibulocochlear nerve function would be of real value. In the present study we investigated the in vivo effect of waterjet application on the vestibulocochlear nerve in rats. We report the consequences of waterjet dissection on vestibulocochlear nerve morphology and function.

Methods

Experimental Study Design

To evaluate the effect of waterjet dissection on cranial nerves, an experimental in vivo study was undertaken. Forty-two adult rats underwent lateral suboccipital craniectomy and microsurgical exposition of the vestibulocochlear nerve (Table 1). Each animal underwent unilateral dissection of the vestibulocochlear nerve with a distinct waterjet pressure. Pressures of 2, 4, 6, 8, and 10 bar were used. The ABRs were measured preoperatively and at defined time points postoperatively up to 6 weeks. Nerve morphology was evaluated microscopically and histologically. Approval of the experimental protocol was obtained from our institutional animal care and use committee as well as from the German State Committee of Laboratory Animal Research.

The Waterjet Instrument

The waterjet (Erbe Elektromedizin) consists of an electronically controlled medium converter, a saline cartridge, and a handpiece applicator with a narrow nozzle and a surrounding suction device. A nozzle type generating an 120-μm helically turned waterjet was used (Fig. 1a and b). Sterile isotonic saline solution was used as separating medium. The medium converter generates a waterjet with a pressure range between 1 and 150 bar. An integrated suction device can be adjusted up to –600 mbar. For a more detailed description of the waterjet instrument, please refer to earlier reports.

Application of Waterjet Dissection

Forty-two adult male Sprague-Dawley rats were anesthetized by intraperitoneal injection of ketamine (0.1 ml ketamine 10% per 100 g body weight) and xylazine (0.05 ml xylazine 2%). The ABRs were recorded preoperatively after placing subcutaneous needle electrodes over the left and right posterior convexity, vertex, and neck. Click stimuli were conveyed through tubal earphones inserted into the external auditory canal. After bilateral recording, the best responding side was selected for nerve surgery. The animal head was fixed in anteflexion and prone position in a stereotactic frame system. After skin incision, a lateral suboccipital craniectomy was performed using a diamond drill (Fig. 1c). The dura mater was opened and draped in the direction of sigmoid sinus. The cerebellum was retracted to the midline. Under microscopic view, the cerebellar pontine cistern was opened. Beneath the flocculus the cranial nerve VIII was exposed on its course from the brainstem to the internal auditory canal. During nerve exposure, flattening of the ABR amplitude and an increased latency were noted in some cases. However, the ABR amplitude and latency returned to their normal values in all cases before the waterjet was applied. The cochlear nerve was observed and exposed to the waterjet in the middle of the distance between the brainstem and the internal auditory canal. Thereby, the nozzle was applied directly to the nerve surface. Microscopic results were documented photographically. The dura and skull were closed with autologous fascia and fibrin gel foam, and were tightly sutured.

Auditory Brainstem Responses

Auditory brainstem responses were measured preoperatively, intraoperatively, and directly after each surgical procedure. Each measurement was performed bilaterally after induction of deep ketamine anesthesia. Postoperatively, the animals were closely observed until awake. Oral analgesics were administered (novaminsulfon 20–50 mg/kg) for 1 week. Animals presenting with neurological complications were immediately killed. Follow-up ABRs were obtained at 1 day, 1 week, 2 weeks, and 6 weeks postoperatively and compared with those measured in the healthy contralateral side. Complete remission of ABRs was defined by reaching the initial amplitudes and latencies.

Processing for Morphological and Histological Evaluation

After the last ABR recordings, the rats were killed. Intracardial perfusion was then undertaken with 4% paraformaldehyde solution. The anatomical preparation was performed by careful dissection of the vestibulocochlear nerves from the temporal bone structures (Fig. 1d), keeping them attached to the brainstem. The dissected vestibulocochlear nerve was microscopically investigated and documented. After immersion fixation in 4% neutral buffered formalin and embedding in paraffin, each specimen was cut

### Table 1: Forty-two rats underwent microsurgical waterjet dissection of the cranial nerve VIII

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>waterjet pressure (bar)</td>
<td>2 4 6 8 10</td>
</tr>
<tr>
<td>total no. of rats</td>
<td>9 8 9 10 6</td>
</tr>
<tr>
<td>no. of rats died</td>
<td>1 0 3 5 1</td>
</tr>
<tr>
<td>no. of rats available for ABR assessment</td>
<td>immediate postop 9 8 9 9 1</td>
</tr>
<tr>
<td>Day 1</td>
<td>9 8 8 9 1</td>
</tr>
<tr>
<td>Day 7</td>
<td>8 8 7 8 1</td>
</tr>
<tr>
<td>Day 14</td>
<td>8 8 6 7 1</td>
</tr>
<tr>
<td>Day 42</td>
<td>8 8 6 5 1</td>
</tr>
</tbody>
</table>

* For each rat only 1 pressure level of 2, 4, 6, 8, or 10 bar was applied.
into 2-μm-thick coronal slices in several steps and stained with H & E. Axonal nerve integrity was microscopically analyzed, quantitatively documented, and compared with the healthy contralateral side.

Results

General Results

Forty-two rats were stratified to 5 groups (Table 1). Animals that presented with neurological complications were immediately excluded. Thus, not all rats were available throughout the time course of ABR follow-up examination. Twenty-eight rats reached the final 6-week ABR recording follow-up.

Effect of the Waterjet Instrument and Results of ABRs

Waterjet dissection was performed with one slow dissection movement of the hand similar to the intraoperative procedure in brain tumor cases. In all cases, there was an immediate significant decrease of ABR amplitude and increased latency, which resulted in a complete loss of ABRs at the end of the dissection in all but one 2-bar case. With respect to the various dissection groups, with 2-bar dissection pressure, no microscopic effect on the vestibulocochlear nerve was seen. The ABRs decreased significantly intraoperatively, but all 2-bar–treated animals exhibited a full ABR recovery within 6 weeks except 1, which died within the 1st postoperative week (Fig. 2A–E). In the 4-bar group, the nerve was found microscopically to be intact. All 4-bar–treated animals reached the 6-week follow-up with completely recovered ABRs. Waterjet calibration to 6 bar also did not injury the nerve surface. One rat presented with neurological complications on Day 1. Two additional animals died of anaesthesia-related complications. All rats reaching the 6-week follow-up presented with complete recovery of ABRs. An 8-bar waterjet provoked microscopically visible damage of the nerve surface; the nerve integrity was intact. One animal in the 8-bar group died intraoperatively. Three of 5 (60%) 8-bar–treated animals exhibited complete recovery of ABRs at 6 weeks. Ten-bar waterjet dissection (6 animals) severely damaged the nerve structure, sometimes even causing complete dissection. Four vestibulocochlear nerves were completely cut (Fig. 1d). In the other 2 cases, severe nerve damage was microscopically observed. Five animals died intraoperatively due to brainstem lesions (2 cases) or bleeding complications (3 cases). Furthermore, increased foaming and brain swelling were noted.

All rats with a prolonged postoperative survival had a complete recovery of the ABRs in the subgroups of 2-, 4-, and 6-bar treatment. The graph in Fig. 3 shows the time course of ABR recovery.

Morphological and Histological Findings

In the 2-, 4-, and 6-bar groups, no macroscopic damage of the nerve was visible in any cases. With 8-bar waterjet dissection, the nerve surface appeared injured and slightly scarred, in agreement with the intraoperative findings. Additionally, small blood clots adherent to the nerve
Waterjet dissection of the vestibulocochlear nerve

Discussion

Preservation of the morphological integrity of cranial nerves and their physiological function is one of the major goals in skull base surgery. While peripheral nerves have the potential for regeneration, cranial nerves are even more sensitive, and postoperative cranial nerve lesions are a feared complication in skull base tumor neurosurgery. Therefore, it is of utmost importance to protect cranial nerves during neurosurgical procedures. In vestibular schwannoma surgery, the most frequent complication is hearing deterioration. The treatment goal in vestibular schwannoma surgery is complete tumor removal and preservation of neurological function. Even large vestibular schwannomas can be removed completely using the appropriate techniques. The size of the tumor has been shown to correlate with postoperative facial nerve function. In particular, large tumors possess an increased risk for persisting postoperative facial nerve palsy. Neuromonitoring represents the gold standard for surgery of the CPA, and it is thought to be essential for good outcome of facial and cochlear nerve function. Surgical manipulations, such as retraction of cranial nerves, should be avoided for a better outcome, represented as a reduced rate of vestibulocochlear and facial nerve injury.

The waterjet technique has been shown to enable a precise tissue dissection under various conditions, but only a few studies have examined the effect of waterjet dissection on peripheral nerves. In one study, sparing of peripheral nerves was reported. No studies of waterjet dissection of the cranial nerves have been reported. In the current study, the vestibulocochlear nerve of rats was subjected to waterjet dissection with pressures of 2–10 bar. Anatomical and functional preservation of the nerve was evaluated in a microscopic analysis and in the ABR recordings. With waterjet pressure up to 6 bar, the vestibulocochlear nerve anatomy and function could be preserved. A pressure of 6 bar is sufficient for dissection of brain gliomas, brain metastases, and brain tissue in temporal lobe epilepsy procedures. An applied pressure...
of 10 bar resulted in a significant number of intraoperative complications with 5 of 6 rats dying of brainstem lesions or bleeding complications. Only 1 animal (8-bar group) died intraoperatively, which did not belong to the 10-bar group. Thus, there was a significantly higher number of intraoperative complications when using higher pressures. In contrast to the pressures applied in clinical cases so far, where a pressure of 10 bar is nearly routine in supratentorial metastases, lower pressures have to be applied in infratentorial waterjet surgery, and extreme caution has to be exercised to avoid any collateral damage to neighboring structures.

Cranial nerve regeneration differs in rats and humans. The human vestibulocochlear nerve might not possess the same regenerative potential as the nerve in rats. Second, in vestibular schwannomas, the nerve often is already severely compressed, and function is often poor preoperatively. Thus, the vulnerability of the nerve and its regenerative potential under clinical conditions might be much worse than in the experimental situation. Finally, the recording of ABRs seems to be a good indicator of vestibulocochlear nerve function, missing, however, is definitive evidence that the preservation of the ABRs in the animal model correlates with preserved hearing function under clinical conditions. Thus, further research is required before definite conclusions can be drawn regarding the possible effect of waterjet dissection on the vestibulocochlear nerve under pathological conditions.

Overall, waterjet dissection remains a potentially useful neurosurgical technique. In addition to promising results observed in endoscopic conditions, the current data on the vestibulocochlear nerve in rats highly support further research in this field.

Conclusions

Improvement of microsurgical dissection of cranial nerve tumors with concomitant preservation of nerve anatomy and function would be a major breakthrough in skull base neurosurgery. The present study demonstrates that the vestibulocochlear nerve of rats subjected to waterjet dissection of pressures sufficient for tumor resection can preserve nerve anatomy and, even more importantly, nerve function. These findings could be of major importance for the future of cranial nerve preservation in skull base neurosurgery. Further studies on the effects of waterjet dissection on cranial nerves are highly encouraged.

Disclosure

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Disclaimer

The authors state that they have no financial interest in the technology presented in the manuscript.

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