Waterjet dissection of the brain: experimental and first clinical results

Technical note

JÜRGEN PIEK, M.D., CHRISTIAN WILLE, ROLF WARZOK, M.D., AND MICHAEL-ROBERT GAAB, M.D.

Neurochirurgische Klinik and Institut für Neuropathologie, Ernst-Moritz-Arndt Universität, Greifswald, Germany

Control of bleeding during dissection is a problem that is still not completely resolved in neurosurgical procedures. To overcome this problem in some settings, the authors, in close collaboration with their institution, developed a new device for blunt dissection of brain tumors that is based on a waterjet technique. This report describes their first experimental and clinical experience with this new method. Numerous cutting experiments were performed in porcine cadaver brains. The best results were obtained using pressures from 4 to 6 bars with a 100-μm tip, which produced very small, precise cuts. Histological evaluation showed no disruption or vacuolization of the surrounding tissue.

The authors have used the new device in nine patients (seven with gliomas and two undergoing temporal lobe resections for epilepsy), and no complications have been observed. The waterjet device allowed dissection of the brain tissue while even small exposed vessels were spared injury. The instrument was found to be easy to use. Future investigations will concentrate on adapting this new method to endoscopic surgery and evaluating fluids with low surface tension to avoid foaming and bubbling during open surgery.

KEY WORDS • waterjet • brain tumor • operative technique • dissection

O ne of the difficulties in the performance of brain surgery is the control of bleeding during dissection. A variety of instruments have been developed to aid in the blunt dissection of brain tumors. For example, the ultrasonic aspirator is used to debulk soft to moderately firm tumors, but has the disadvantage of its large handpiece and inflexibility. Mono- and bipolar coagulation as well as different lasers may help to control bleeding during surgery but they cause thermal damage to the surrounding tissue. To overcome these problems a new device for blunt dissection of brain tumors has been developed based on the waterjet technique, in close collaboration with our institution. This report describes our initial experimental and clinical experience with this new method.

Technical Description of the Waterjet System

In the waterjet system (Müritz 1000; Euromed Medizintechnik, Schwerin, Germany), 1 to 150 bars of liquid, in this case sterile 0.9% saline, is emitted through a flexible tube to a pencilike handpiece tipped with a fine nozzle (80, 100, or 120 μm diameter). The pressure is manually preset via the control unit, and during surgery it can be adjusted within the preset range with the aid of a foot pedal. The handpiece allows guidance of the beam according to the necessary distance and angle to the tissue. Dissection is accomplished by the mechanical force of the water stream itself. In Germany the system has been approved by regulatory authorities for use in surgery on humans.

Materials and Methods

In vitro experiments were conducted on fresh porcine cadaver brains to evaluate the performance of the waterjet device for dissection and especially the depth of dissection for different nozzle diameters and different pressures. The porcine brain hemispheres were fixed on a specially designed cutting sledge. All dissections were performed with 1 cm between the nozzle tip and the brain surface and with a constant cutting rate of 1 cm/second. We used five cuts per given pressure (1–10 bars) for each diameter of the nozzle. Histological evaluation was then performed, which included measurement of the cutting depth as well as a careful examination of the cut surface.

Results

The results are summarized in Fig. 1. Between 1 and 4 bars the depth of dissection increased slightly, from 3.2 to 4.2 mm. From 4 to 6 bars the depth of the cuts increased linearly with both 80- and 100-μm nozzles. At pressures greater than 6 bars a different reaction/behavior was observed: whereas there was still a linear increase with the 100-μm nozzle, a decline was observed at 7 bars for the 80-μm tip, followed by an increase up to a mean depth of 12.9 mm at 10 bars.

The histological examination indicated that in all applied jet lesions the cutting effect was a result of mechanical fragmentation of tissue directly under the nozzle, with only a very few cells separated from the surrounding tissue. The cuts were extremely sharp and precise: no disruption or vacuolization was seen in the surrounding tis-
sue (Figs. 2 and 3). Vessels as small as 300 μm in diameter were preserved.

Clinical Application

We have now used the new device in nine patients, seven with gliomas (Grades II–IV) of the frontal, temporal, and occipital lobe, and two in whom temporal lobe resections were performed for epilepsy. We have always used a 100-μm nozzle because in the in vitro experiments the variation of the cutting depth with this tip was less pronounced compared with the 80-μm tip. After incision of the arachnoid we started the dissection with a pressure of 3 bars and adjusted it according to the intraoperative site. The maximum pressure applied was 7 bars. The device was used in all patients for dissection of the brain surface by following precisely the desired line of incision with the waterjet. In three of our patients with brain tumors we used it additionally with a pressure of 3 to 5 bars for mechanical fragmentation of the tumor itself, which could easily be removed later by means of a conventional suction tube. The clinical outcome in all patients was uneventful.

Intraoperatively the waterjet dissected the brain tissue while even small exposed vessels were spared from injury (Fig. 4). These could be coagulated afterward by using bipolar forceps. Compared with conventional instruments (laser, ultrasound aspirator) this device has a much lighter and smaller handpiece with a very fine tip (1.2 mm), which makes it easy to handle. Different angles and lengths of the tips provide great intraoperative flexibility. The ideal distance for dissection seemed to be between 1 and 3 cm. A longer distance usually disturbed visualization of the operative field from splashing and foaming of the reflected water beam.

Discussion

In industry high-pressure waterjets (as high as 20,000–30,000 bars) are used to cut various materials including steel, plastics, stones, and skins. Modified systems set at much lower pressures are used clinically for liver and kidney surgery. Experimental applications include dental surgery and angioplasty. A waterjet technique for experimental neurosurgical purposes has also been used by Terzis and Mukai and coworkers, but to our knowledge it has never been used in clinical practice.

Control of bleeding during dissection is still a problem in neurosurgical procedures. Various laser instruments and the cavitron ultrasound aspirator were developed as tools to be used in addition to conventional dissection. The main disadvantages of both are damage to surrounding tissue either by thermal or mechanical injury and problems regarding tissue selectivity and preservation of smaller vessels. Also, with ultrasound aspiration cavitation effects are observed. Another difficulty is the size and inflexibility of the instrument, which makes it hard to use in endoscopic procedures or for deeper lesions.

To overcome these obstacles the new device was devel-
Waterjet dissection of the brain

opened. Compared with traditional instruments its main advantages are: 1) no thermal effect on surrounding tissue; 2) selectivity in dissecting different tissues (brain, blood vessels, pia mater); and 3) great flexibility with a small handpiece and a very small tip.

The effect of waterjet dissection on brain tissue is dependent on different parameters as follows: 1) cutting rate and distance; 2) pressure of the water beam; and 3) diameter of the nozzle. Other important factors are the structure and mechanical firmness of the brain and the tumor to be dissected. Whether waterjet dissection is performed “under water” (endoscopic surgery) or during open surgery also plays an important role. Thus, only safety parameters for the dissection of normal brains can be obtained from in vitro and in vivo experiments. Such experiments never reflect the true intraoperative situation, in which tumors of different firmness must be dissected from the surrounding edematous brain tissue. From our experiments in porcine cadavers we conclude that dissection on the brain surface should be started after incision of the arachnoid with a pressure of 3 bars from a distance of approximately 1 cm. Depending on the intraoperative situation this pressure can be gradually increased. Vessels as small as 0.3 mm are spared from injury at between 3 and 7 bars of pressure. Current experiments focus on the mechanical stability of other brain structures (for example, ventricular ependyma, arachnoid, various vessels) to obtain safety parameters for other procedures (endoscopic surgery) and regions of the brain (cerebellum, ventricle, brainstem).

Although it is our belief that blood loss is diminished using the new device compared with conventional techniques, we did not conduct a randomized analysis covering this question. Rau, et al., compared the waterjet techniques with the cavitron ultrasound aspirator in open liver resections. They clearly demonstrated that resection using the waterjet is faster and associated with less blood loss. A potential complication may be venous air embolism caused by the waterjet. However, this complication was observed at much higher pressures than the one used for brain dissection. Because the waterjet cannot perforate large vessels at the pressures currently used for brain dissection, air embolism should not be a problem in neurosurgery and has not been observed by us.

Fig. 3. Photomicrographs of various histological samples demonstrating sharp dissection of the brain without damage to the surrounding tissue. Original magnification × 5 (left); × 100 (right).

Fig. 4. Intraoperative photograph demonstrating sparing of even small vessels by the new device.
The only disadvantage of the waterjet dissector is that of splashing and foaming. This problem occurs especially if the device is used at a distance of more than 1 to 2 cm from the brain surface and at higher pressures. Stopping dissection for a short period, keeping the device at short distances from the surface, and using it with a suction tube (which is currently built into the tip) usually avoid these effects. However, the problem may eventually be solved by developing liquids with different surface tensions compared with saline.

Conclusions

We think that waterjet dissection is a promising technique in neurosurgery and that its further development is worthwhile. Our future studies will focus on its role in endoscopic surgery, where it has the special advantage of its great flexibility and small dimensions, and in which splashing and foaming do not play a role in the cerebrospinal fluid.

Acknowledgment

The authors thank Dr. Berger for his assistance in preparing the manuscript.

Disclosure

The authors state that they have no interest in the methodology or equipment advanced in this report.

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