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Water-jet dissection in renal surgery: experimental study of a new device in the pig

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Abstract The pig model was used for experiments with a new type of water-jet dissector, which produces high-pressure water by application of a gas and maintains the water fully sterile in a single-use delivery apparatus. The experiment was conducted ex vivo (14 kidneys) and in vivo to compare electric cautery section with water -jet dissection (5 vs 11 partial nephrectomies). Ex vivo study confirmed sparing of blood vessels and pelvicaliceal system. In vivo study did not show significant differences in blood loss but, the water-jet allowed precise dissection and tight closure of the excretory system. More frequent haemorrages were noted on histological examination of the WJ group, but no coagulation necrosis. These are preliminary findings and further studies of long-term results may confirm the benefits of the absence of parenchymal necrosis and the definite advantage of precise closure of the pelvicaliceal system, as morbidity of partial nephrectomy is often related to secondary haemorrages and urinary fistulae.

Key words Nephrectomy · Dissection · Water-jet dissector · Evaluation studies · Pig

Introduction

First performed by Wells in 1884, the partial nephrectomy procedure has been somewhat neglected because of its high morbidity and the severity of its complications, which are especially due to the difficulties encountered in achieving haemostasis and urostasis [10]. However, today there are still a number of indications for partial nephrectomy and the increase in incidentally discovered small renal tumours in recent years has stimulated interest in nephron-sparing surgery [14]. This has led to many attempts to improve the surgical technique of partial nephrectomy, water-jet dissection being one such approach. High-pressure jets of water already have many industrial applications, but the first known attempt to use this technology for surgery was made by Papachristou in 1982 on canine liver [12]. However, several authors [2, 3] have reported a high number of septic complications with the apparatus due to the use of non-sterilisable pumps producing water under pressure.

We report here the results of investigations conducted on pig kidney with a new water-jet dissector allowing an aseptic procedure to be followed. After an ex vivo preliminary study to determine the quality and selectivity of dissection obtained with the device, we compared results with its in vivo use with the results obtained with electric knife section in the pig model.

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Materials and methods

The water-jet dissector

The aim of this technique is to disrupt and wash out the soft tissues, sparing the vessels and high-connective-content tissues [3, 17]. Once isolated, these structures can be manipulated as necessary; the methods and results with the technique are very similar to those used with ultrasonic dissectors [3, 8]. The main disadvantage of all currently available water-jet dissectors lies in the use of non-sterilisable pumps to produce water under pressure [3]. The device we tested is original in that high-pressure water is produced by application of a gas on a sterile water pouch placed in a pressurised airtight steel chamber (Fig. 1). The gas can be either carbon dioxide or nitrogen from ordinary medical gas bottles. Its admission into the pressurisation chamber is under constant control by an electronic

Fig. 1 Water-jet dissector: ➔ pressurised gas admission, ☆ pressurised airtight steel chamber containing the sterile water pouch, → electronic system control, ⇒ hand piece with nozzle delivering a 0.2-mm-diameter water jet

system through electromagnetic valves, which allow a constant working pressure from 0 to 30 bars. Normal saline water bags are identical to these commonly used for i.v. infusions and do not require special preparation. Water under pressure is then transmitted to the hand piece through a connecting section and hoses. All materials are sterile and are used once. The hand piece delivers the jet of water by means of a high-technology nozzle containing a sapphire which produces a jet of constant and precise diameter (0.2 mm for this experiment). A suction line is connected to a transparent hollow tip covering the jet nozzle and through which physiological saline, blood and fragmented tissues are suctioned out.

Ex vivo experiment

The study was done on fresh cadaver pig kidneys to evaluate the performances of the water-jet for dissection and especially its ability to spare the noble structures (vessels, pelvicaliceal system); this was related to working pressure. The final objective was to determine a working pressure that could be used for in vivo investigation. This was done in three steps: (1) assessment of the depth of 13 sections with varying working pressures of 4–30 bars in five kidneys; (2) assessment of the selectivity and quality of six sections (diameter of spared vessels, aspect of the pelvicaliceal system) with pressures ranging from 4 to 30 bars in five kidneys; and (3) assessment of the reproducibility of quality and selectivity of sections obtained with a 16-bar working pressure in eight guillotine partial nephrectomies.

In vivo experiment

Principles of laboratory animal care (NIH publication No. 86-23, revised 1984) were followed. Agreement for experimental study on the pig was obtained from the French Ministry of Agriculture (No. 005449).

Anaesthesia

Sixteen partial nephrectomies were performed on four young pigs (average weight 25 kg). Animals were placed under general anaesthesia according to the following protocol: (1) intramuscular premedication with ketamine (20 mg/kg) and droperidol (1 mg/kg); (2) induction of general anaesthesia with intravenous pentobarbital (20 mg/kg); and (3) intubation and maintenance of anaesthesia with an equimolecular nitrous oxide and oxygen mixture associated with intravenous midazolam (0.4 mg/kg per hour), fentanyl (10 μg/kg per hour), atracurium (2 mg/kg per hour), and propofol (10 mg/kg per hour). Circulating blood volume was maintained with a macromolecular solution (hydroxyethylamidon). At the end of the surgical procedure all animals were sacrificed using 6 g intravenous potassium chloride while under anaesthesia.

Surgical procedure

Kidneys were exposed through a midline abdominal incision; the renal arteries were not occluded during this procedure. Upper and lower kidney pole resections were achieved in the mid-thirds of the kidneys, all of the guillotine type. Eleven sections were done with a water-jet dissector; five others were performed with a classical electric knife.

Water-jet section. After preliminary section of the renal capsule, transsection was done using gentle slow motion of the water-jet through the cortex and medulla. Exposed vascular structures were electrocoagulated when small, or ligated with 5/0 polypropylene if larger. The pelvicaliceal system was then isolated without being opened, held in place by a clamp, cut with a steel scalpel and then closed with a 4/0 polyglactin continuous suture.

Electric knife section. Parenchymal transsection was performed with the tip of the electrocautery device. Electrocoagulation was achieved step by step as much as possible. Bleeding from the larger-sized vessels was controlled by the application of surgical clamps or Kelly forceps and then tied with 5/0 polypropylene. The collecting system, which was never well individualised, had to be opened and then closed with a continuous suture of 4/0 polyglactin. This suture was not easy to do because of the instant retraction of the pelvicaliceal system into the parenchyma.

Three data items were recorded during the procedure and used for comparison: (1) operating time from capsule incision until achievement of complete haemostasis; (2) blood losses for both techniques, by weighing sponges and, in addition for jet dissection, by the volume of blood in the suction unit (aspirated fluid minus volume of water injected for section); and (3) tissue specimens taken at the incision site for histological examination.

Statistical analysis

The Student's t-test was used for comparison of quantitative variables.

Results

Ex vivo study

Section of the renal capsule began at 8 bars but was completed and constant above a pressure of 11 bars. If the depth of the section obtained after one steady continuous passage of the water jet increased with an augmentation of the pressure, no proportional relationship was seen. The collecting system was never opened, up to a pressure of 30 bars. The study of the characteristics and selectivity of dissection with

Fig. 2 Ex vivo partial nephrectomy at 16 bars jet pressure. Spared vessels are clearly seen as renal parenchyma has been washed away

increasing pressures showed the beginning of a section at 10–12 bars sparing the vascular and connective structures at the same time even though the section was insufficient. From 14 to 18 bars, dissection was of excellent quality, sparing the vessels and collecting system. With pressures higher than 20 bars, the number of spared structures decreased rapidly and the quality of the section deteriorated. After these two procedures were performed, quality, selectivity, speed and progression of the section appeared to be optimal at a pressure of 16 bars (Fig. 2). This value was therefore chosen for in vivo investigations and for a complementary ex vivo experiment conducted on eight partial nephrectomies, which confirmed these results.

In vivo study

Operating findings

Ex vivo results were not fully transposable to in vivo partial nephrectomy: it was impossible to cut the kidney capsule efficiently at 16 bars; therefore section of the capsule had to be performed with the electric knife. For the parenchyma, it appeared that speed and power of cutting were, at this pressure, much higher than those observed ex vivo. Consequently, the working pressure was reduced to 10 bars, which level we observed effects similar to those obtained ex vivo for 16 bars. Concerning the surgical procedure itself, in the water-jet group, it was easy to coagulate or secure the isolated blood vessels with ties; moreover the high quality of the individualisation of the collecting system allowed a urine-tight closure. Isolation of the blood vessels using electrocautery was not possible. Bleeding vessels retracted into the parenchyma and were difficult to identify and control. It was always possible to open the pelvicaliceal system but not to individualise it. It was also retracted and therefore a tight closure was difficult to obtain.

Table 1 Characteristics of the experimental groups. Results are expressed as means ± SD (range)

	Specimen weight (g)	Blood loss (g)	Operative time (min)
Electric knife ($n = 5$)	22.6 ± 2.3 (20–25)	64.8 ± 34.8 (26–125)	10.3 ± 1.1 (9–12)
Water jet ($n = 9$)	20.3 ± 2.7 (15–23)	74.1 ± 27.8 (20–103)	15.3 ± 3.8 (10–21)
P^a	0.5	0.9	0.05

[a] According to Student's *t*-test

Recorded data (Table 1)

Average weight of the resected kidney specimens was 22.6 (±2.3) g for the electric knife group and 20.3 (±2.7) g for the water-jet group. Average blood loss during the operations was 68.4 (±34.8) g for the electric knife group and 74.1 (±27.8) g for the water-jet group. The difference between the two groups was not statistically significant, with $P = 0.5$ and $P = 0.9$ respectively. Surgical procedures took significantly longer for the water-jet group, with an average operation time of 15.3 (±3.8) min compared to 10.3 (±1.1) min for the electric knife group ($P = 0.05$). During the water-jet procedures, the mean volume of water required to complete the section was 266 (±127.4) ml.

Histological findings

On histological examination of the tissue specimen after section with the electric knife, it was possible to see intense cellular damage right along the line of section, sometimes with deeper zones of fulguration. Only rarely were intratissular haemorrhages seen. After water-jet dissection, only a small number of epithelial lesions were observed, but localised haemorrhages were more frequent with an intraparenchymal extension.

Discussion

The main indication for the use of the water-jet dissector in renal surgery is partial nephrectomy. Classic indications include duplex kidneys, congenital abnormalities, benign renal lesions, malignant tumours in solitary kidneys, or markedly impaired renal function

[4, 11]. Nephron-sparing surgery in incidentally discovered small renal tumour with normal contralateral kidney is still controversial but could represent another field of development [6, 10, 16]. Many attempts have been made to improve the surgical technique of partial nephrectomy and decrease the risks associated with the procedure (massive bleeding , excessive loss of renal function, especially when renal artery clamping is used). Several techniques have been proposed such as coronal haemostatic sutures, use of autostapling devices, infrared or argon beam coagulators, fibrin glue application, cryosurgery, application of carbon dioxide or neodymium yttrium aluminium garnet (Nd:YAG) lasers, and microwave coagulators [11].

Excessive blood losses and urinary fistulae are due mainly to the difficulty of identifying and securing vessels within the renal parenchyma, as well as the difficulty of isolating the pelvicaliceal system. Thus, a technical device allowing the isolation of these structures and their selective control could improve the results: ultrasonic and water-jet dissection have proved to have a similar efficiency in hepatic surgery [8, 15]. With regard to the kidney, operative conditions are very similar to those encountered during hepatic section and experimental studies have already shown the efficacy of ultrasonic dissection (CUSA, Cavitron Ultrasonic Surgical Aspirator, Valleylab, USA) for partial nephrectomy [1, 11]. Furthermore, Pentchev [13] in 1993 reported encouraging results on dog kidneys with a water-jet dissector. However, all currently available water-jet dissectors suffer from the defect of needing pumps to produce water under pressure: none of these pumps are sterilisable by simple methods and only contact decontamination can be performed; this has led several authors to criticise the high rate of septic complications [2, 3]. The original feature of this new model of water-jet dissector is that water circulates in fully sterile, single-use hoses and hand piece, with no direct contact with gas or any part of the apparatus.

Results obtained ex vivo were not immediately transposable in vivo. Differences were noted in the sections of the capsule and in quality of section. On the one hand, this can be explained by the post-death modifications in elasticity and resistance of connective tissues and vessels. On the other hand, vessels were not perfused during the ex vivo experiments. Operation times were significantly longer in the water-jet group, but it must be borne in mind that the total duration of each procedure was short and that the water-jet dissector was a prototype; therefore, the occurrence of minor technical problems led to a perceptible increase in the duration of the procedure. While no statistically significant difference has been demonstrated regarding blood losses, these might have been higher in the water-jet group for the above-mentioned reasons. Compared to hepatic dissection, renal dissection with the water jet seemed to be less efficient [13]; the same difference has been suggested with CUSA between renal and hepatic surgery [7].

With regard to the pelvicaliceal system, water-jet dissection provided a more selective dissection without accidental opening of the urinary cavities. This always allowed a urine-tight closure to be performed.

Histological examinations showed localized and intraparenchymal haemorrages but no coagulation necrosis. However, these are preliminary findings and evolution of these tissular lesions is not known, nor are the sequelae after healing known. It has been shown that initial thermal lesions 75–500 μm deep [5, 9] were 3 times as deep after 6 weeks [9]. One can expect that the absence of such necrosis at the start of water-jet dissection will not be followed by any worsening of the lesions. Furthermore, it also may avoid secondary bleeding related to the scab being knocked off accidentally.

Conclusion

This new type of water-jet dissector with which we experimented allows renal surgery in optimal aseptic conditions. The ex vivo kidney section demonstrated sparing of the intraparenchymal vessels. But the initial results of partial nephrectomy did not show a sizeable difference from the classical electric knife section. Although the operating time was significantly different, the mean difference was only 5 min. On histological examination, no coagulation necrosis but more frequent haemorrages were observed with the water-jet dissector. The latter allowed more precise dissection of the pelvicaliceal system. However, these are initial findings and it will be important to follow their evolution: further studies of the long-term results may confirm the beneficial effect of the absence of tissue necrosis on the parenchyma and the definite advantage of the precise urinary excretory system dissection.

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