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Tissue Effects of an Ultrasonic Scalpel for Clinical Surgical Use

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Summary. The effects of a new ultrasonic scalpel were studied in laboratory animals. Tissue heat conduction from the tip of the ultrasonic blade was measured. Tissue damage was assessed by light microscopy of histochemically stained sections. The ultrasonic scalpel incised nonfibrous tissue effectively, with minimal heat conduction, and the incisions healed with no evidence of fibrosis nor of tissue destruction.

Key words: Ultrasound, Scalpel, Tissue damage.

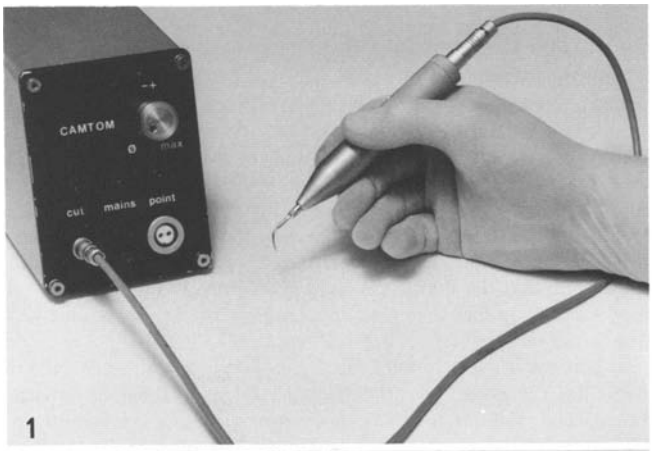
Introduction

The diagnostic uses of ultrasound are everyday features of clinical practice. However, ultrasound energy may be used for therapeutic purposes, because it has the ability to cause cavitation, local heating and tissue fluid vapourisation. In theoretical terms these ultrasonic modalities have the properties of combining tissue destruction and simultaneous coagulation without dissipation of thermal energy. The therapeutic use of ultrasound energy has been limited to neurosurgery and ophthalmic surgery [1]. A hand-held ultrasonic scalpel has been developed and tested in experimental animals with a view to possible urological and paediatric surgical application.

Materials and Methods

A newly developed hand-held ultrasonic scalpel (CAMT Heidelberg) was used throughout (Fig. 1). The ultrasonic generator oscillated at 25–30 kHz, and could be set at one of five different power output settings (1–5). The blades were angulated and were either pointed (Fig. 2a), or flat (Fig. 2b).

Temperature measurements were recorded on a multichannel recorder linked to a wire thermocouple of 0.2 mm tip diameter (RS Components London UK). Electronic ice points were used as temperature reference.



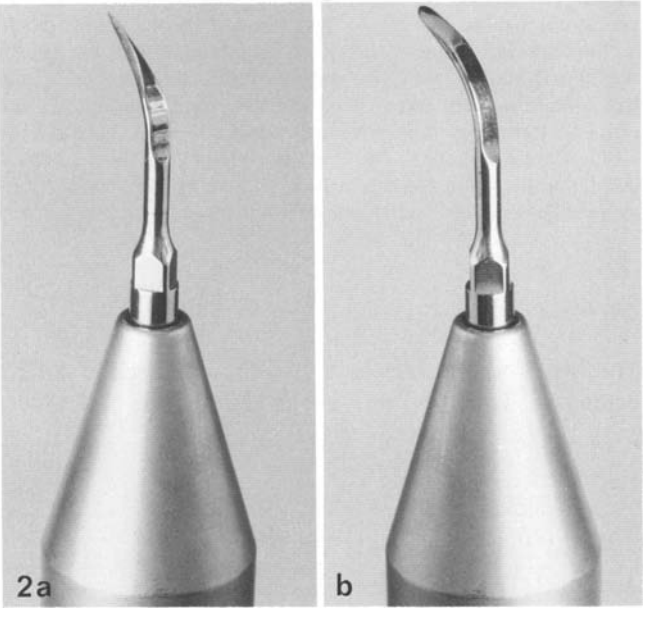


Fig. 1. Ultrasonic scalpel

Fig. 2. **a** Fine pointed angulated blade. **b** Flat sharp edged blade

Table 1. Temperature rise (°C) at 1, 2 and 3 mm from the point of application of the ultrasonic scalpel to the minipig bladder muscosa

Animal	Distance of ultrasonic scalpel from thermocouple		
	1 mm	2 mm	3 mm
P_1	17	9	3.5
	18	8	3
P_2	17.5	8.5	4
	17	9	3

Twelve male Wistar rats were used for survival experiments. Anaesthesia was provided by intraperitoneal valium.

The tunica albuginea of the rat testicles was incised with the pointed blade of the ultrasonic scalpel on one side and with a cold knife on the other. The testicles were removed 24 h later, fixed in formaldehyde, then sectioned and examined histologically with H & E stain.

Minipigs were used to assess tissue heating and long-term tissue damage. Under Halothane anaesthesia mid-line abdominal incisions were made in all cases. To measure heat conduction, two minipigs were used. The bladder was opened and the thermocouple was fixed onto the bladder mucosa with 7/0 sutures. The pointed blade of the ultrasonic scalpel was placed 1 mm distant from the thermocouple and a point incision made at power setting 5 on the ultrasonic generator. The experiment was repeated with the blade positioned radially around the thermocouple 2 and 3 mm distant. This method was designed so that there was no alteration in thermal conductivity due to the tissue effects of previous ultrasonic incision.

Eight minipigs were used for the histological assessment of the tissue damage caused by the ultrasonic scalpel. Through an anterior vesicostomy the ureteric orifices were incised using the various power outputs of the ultrasonic generator. The bladder mucosa and muscle through to serosa was then incised with the pointed blade of the ultrasonic scalpel between two points previously marked on the serosal surface with two non-absorbable sutures. Vesical and laparotomy incisions were closed and the animals allowed to recover. An intravenous urogram was performed four weeks later and the bladders were removed. The ureteric orifices and the section of bladder wall around the site of incision were excised, fixed in formaldehyde, sectioned and examined histologically with H & E stain.

Results

The tissue heating effects of the ultrasonic scalpel are recorded in Table 1. There was a temperature rise in the minipig bladder mucosa of 17–18 °C 1 mm from the tip of the ultrasonic scalpel, which fell to 8–9 °C 2 mm distant, and 3–4 °C 3 mm distant. A trace of temperature changes recorded 1, 2 and 3 mm from the point of application of the ultrasonic scalpel to the minipig bladder mucosa is shown in Fig. 3.

Photomicrographs of sections of rat testicle 24 h after incision with the ultrasonic scalpel are shown in Figs. 4 and 5. At low power there is some disruption of the tubules. At higher power the hyaline degeneration of the incision is seen with a few inflammatory cells in the adjacent tubules. An intravenous urogram in a minipig four weeks after incision of both ureteric orifices with the ultrasonic scalpel is shown in Fig. 6. There is no upper tract dilatation suggestive of obstruction.

Photomicrographs of minipig ureteric orifice and bladder wall four weeks after incision with the ultrasonic scalpel are shown in Figs. 7 and 8 respectively. In Fig. 7 thin flat regenerating mucosa is seen overlying apparently perfectly healed muscle with no evidence of fibrosis. Figure 8 is a section of minipig bladder wall which was incised through to serosa. There is a break in the mucosa but the underlying muscle shows minimal tissue damage.

Discussion

These experiments confirm the manufacturer's claim that the ultrasonic scalpel produced precise ultrasonically assisted incisions. Because the blade was angulated, an elliptical wave of energy was emitted at the tip as it oscillated. Through the application of the oscillating blade surface to the tissue a part of the mechanical wave energy was transformed into work. With a flat sharp-edged blade rather than a fine pointed blade coagulation combined with incision was produced. The energy transformed into work in the immediate vicinity of the knife had three effects:

1. Cavitation: the rupture of cell structures.
2. A heating effect.
3. Vapourisation of cell liquid.

Incision must occur in one of two ways: either the vapourisation caused sufficient dessication that the small amount of heat produced could then cause the cell to disintegrate, or the vapourisation caused cleavage of the cell in the im-

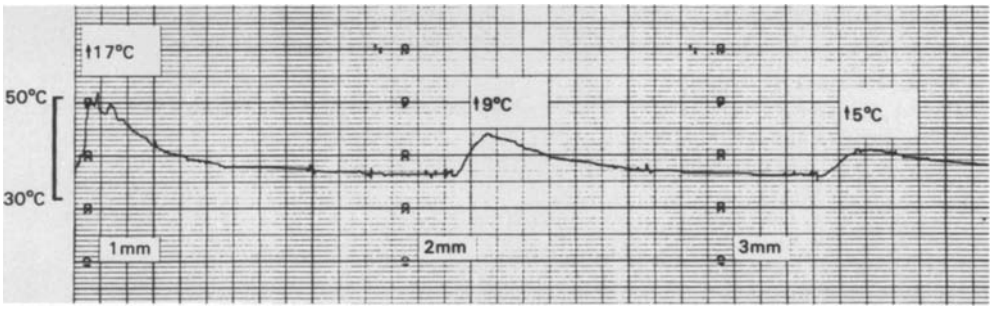
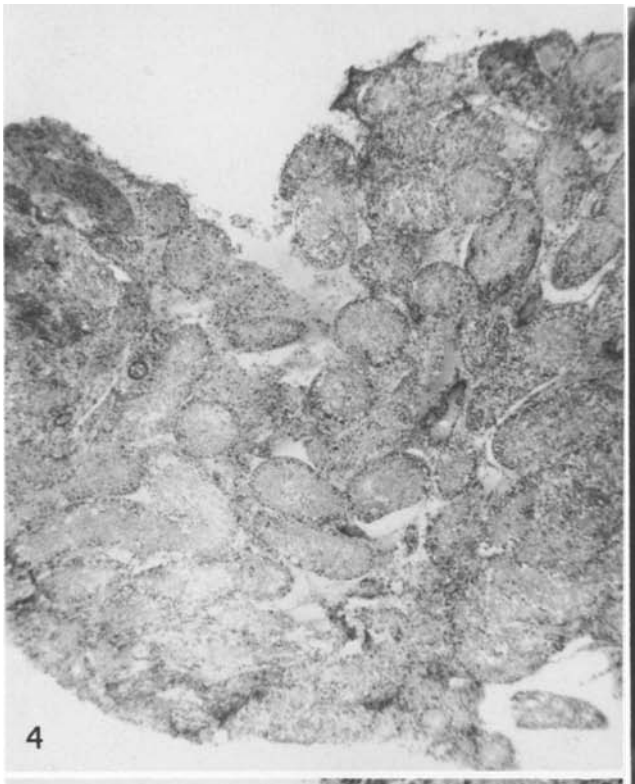
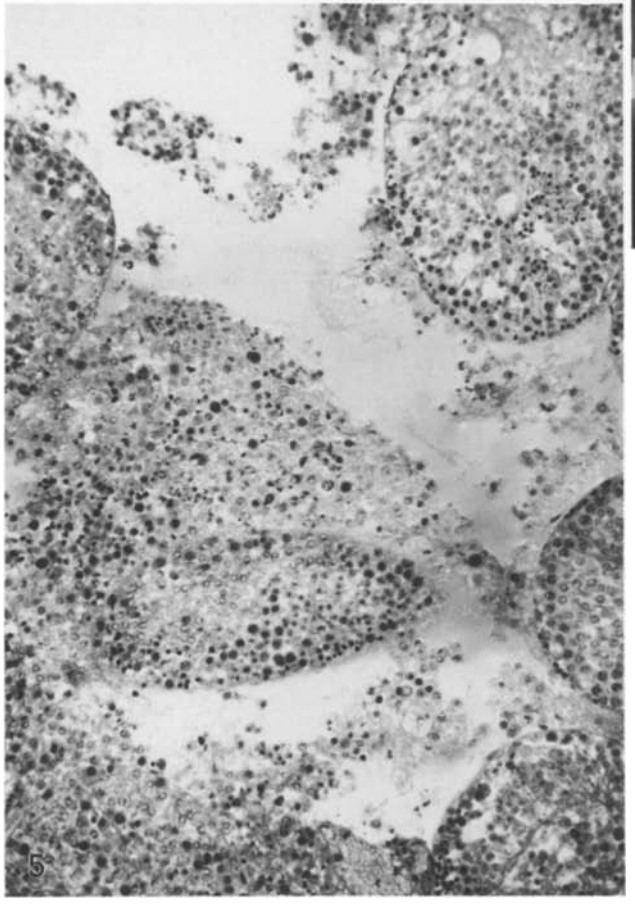


Fig. 3. Tissue heating effects of ultrasonic scalpel. Recording of temperature rise at 1, 2 and 3 mm from the point of application of the tip of the ultrasonic scalpel in the minipig bladder mucosa





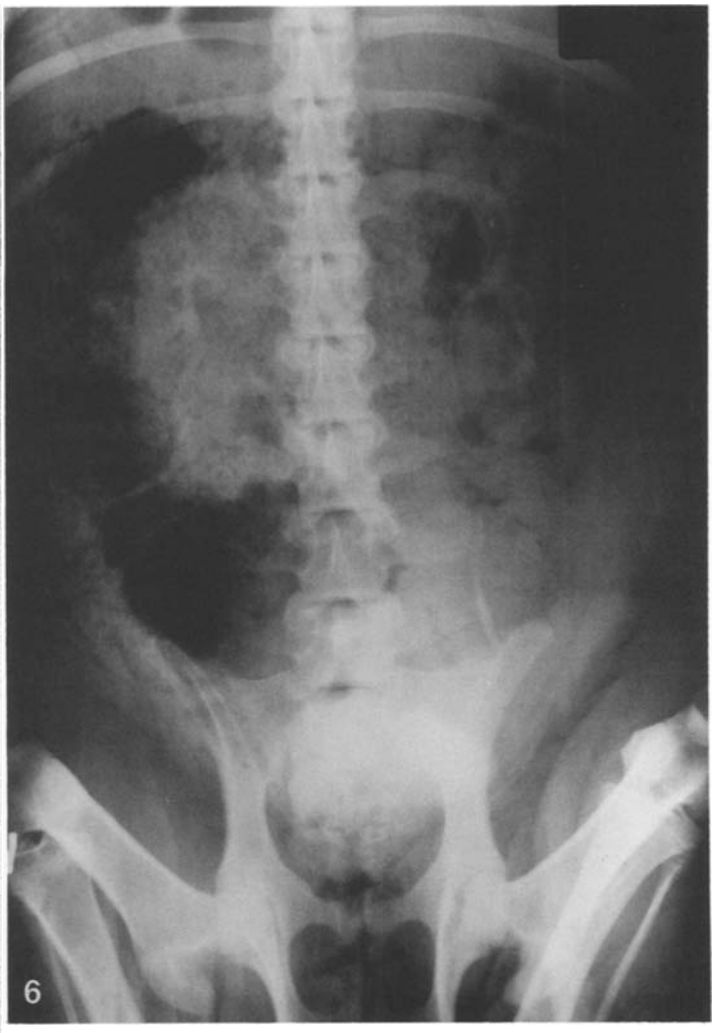


Fig. 4. Rat testicle 24 h after incision with ultrasonic scalpel (low power) x 29

Fig. 5. Rat testicle 24 h after incision with ultrasonic scalpel (high power) x 436

Fig. 6 Intravenous urogram four weeks after incision of both ureteric orifices with the ultrasonic scalpel (Prone)

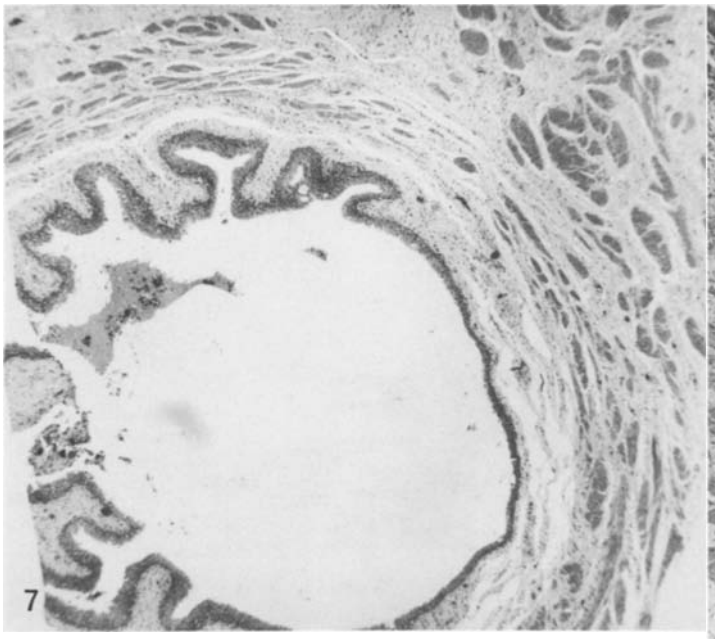


Fig. 7. Minipig ureteric orifice four weeks after incision with ultrasonic scalpel. x 28

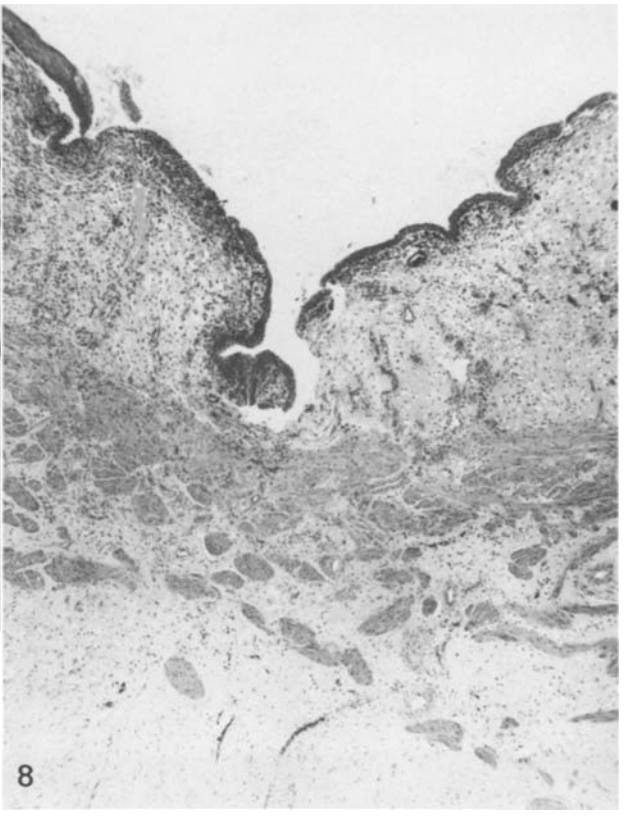


Fig. 8. Minipig bladder wall four weeks after incision with ultrasonic scalpel. x 28

mediate vicinity and so incision was made and was shown as cavitation. The vapourising action of the ultrasonic scalpel was visible to the naked eye. In assessing the tissue heating effects one must remember that in order for monopolar diathermy to cut a temperature of $> 1{,}000\,^{\circ}C$ is generated. A temperature rise of $17\,^{\circ}C$ was recorded 1 mm away from the pointed ultrasonic blade which had fallen to $3.5\,^{\circ}C$ 3 mm away. No radiological or histological evidence was found that this was a significant rise in temperature. The intravenous urograms all showed no evidence of ureteric obstruction or dilatation, thus indicating an absence of fibrosis at the ureteric orifices.

Minimal tissue damage could be detected in the histological sections. In the rat testicle 24 h after incision of the tunica albuginea there was some disruption of the tubules. At higher power the hyaline degeneration of the incision was seen but apart from a few inflammatory cells in the tubules there was minimal damage – although the blade had coagulated as it incised.

The long-term tissue damage effects of the ultrasonic scalpel confirmed healing without fibrosis. In the minipig the ureteric orifice showed thin regenerating mucosa over perfectly healed muscle. The section of bladder wall which was incised right through to serosa showed a break in the mucosa but the underlying muscle showed minimal tissue damage.

Conclusions

Precise incision combined with coagulation, without the need for an indifferent electrode, with minimal transmission of tissue heating, and effective in any solution could be used to great advantage in urological and paediatric surgery. In its present prototype form the ultrasonic scalpel requires the blades to be changed with a spanner and is thus of limited application. However, these preliminary results suggest that with the refinements that are already underway a more powerful better aligned ultrasonic scalpel may be produced which will have widespread surgical applications including endoscopy.

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Reference

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