Experimental study of single-pin puncture asymmetrical hydroablation using a conformational radiofrequency ablation electrode in *ex vivo* ox liver

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Objective: The aim of this study was to evaluate the feasibility of single-pin puncture asymmetrical hydroablation in liver using the multipole cluster conformable radiofrequency ablation electrode.

Methods: The conformable electrode used in this study consists of both a main electrode in a central cannula and a circle of subelectrodes comprising two groups of six subelectrodes located on opposite sides (A and B) of the circle. The two subelectrode groups can be extended to different lengths independently of one another, resulting in asymmetrical shapes. Ablation experiments were performed using *ex vivo* ox liver. The experiments included six groups based on six potential electrode deployments in which the subelectrodes on sides A and B were fully extended, half extended or fully retracted. After ablation, the transverse diameters of the resulting necrotic tissue from sides A and B were measured. The experiment was conducted in 12 separate sites for each group.

Results: When the subelectrodes were arranged symmetrically (either fully extended or half extended on both sides), the mean transverse diameter of necrotic tissue was similar for both sides A and B. When the subelectrodes were arranged asymmetrically, the fully extended side showed a significantly greater mean transverse diameter of necrotic tissue than the half extended or fully retracted side.

Conclusion: In this study, the WHK 3-8-4 multipole cluster conformable radiofrequency ablation electrode was able to produce both symmetrical and asymmetrical necrotic tissue patterns in the liver.

Advances in knowledge: The size and shape of the ablation can be altered by both withdrawing and extending the subelectrodes to different lengths.

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Hepatocellular carcinoma is one of the most common solid cancers in the world with an annual incidence rate estimated at approximately 1 million patients per year. Surgical resection has been considered the best curative option but only a small proportion (5–20%) of patients undergo surgery for liver cancer. The reasons for patients not being candidates for resection include multifocal disease, proximity of the tumour to vascular or biliary duct structures and inadequate functional hepatic reserve owing to comorbid cirrhosis [1].

Radiofrequency ablation (RFA) is one strategy that aims at decreasing the tumour volume and preventing growth, thereby leading to longer survival and a potential cure for some patients. RFA, using radiofrequency electric current to create local heat for destroying tumour cells, has the advantage that it is minimally invasive, simple and safe. It has a lower rate of complications and morbidity than other ablative

techniques and the ablative success rate is approximately 94% [2–5].

Several factors influence the outcomes of RFA in treating cancer. These include the skill of the physician, the abundant blood flow present in the normal hepatic parenchyma (which acts as a heat sink) and the ability to adequately kill both the tumour and the hepatic tissue adjacent to the tumour [6]. The last point is particularly difficult given that most tumours are irregular in shape, and the technique usually results in symmetrical necrosis of the tissue following ablation.

In order to overcome the issue of irregularly shaped tumours, multiple treatments are superimposed [7, 8]. However, these result in both increased numbers of punctures to the liver and possibly increased X-ray exposure as a result of CT scanning, which is often used to guide the positioning of the probe. Multiple treatments also increase the risk of damaging other organs and tissues close to the tumour [1, 7, 8].

One way to overcome this problem is to design RFA electrodes that can be asymmetrically adjusted, which would allow treatment with a single puncture of the liver. The Wellfare Electronic Technological Company

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(Beijing, China) has developed the multipole cluster electrode in which subelectrodes extend from the central probe and can be separately adjusted to form asymmetrical shapes. The objective of this study was to assess whether this electrode could form a controlled asymmetrical necrosis with a single puncture of the tissue.

Methods and materials

Experimental material

The ablation experiments used fresh ox livers weighing 8–16 kg that had been removed from the animals for less than 12 h.

Experimental equipment

The radiofrequency ablatograph (WE7568II; Wellfare Electronic Technological Company) used in this study is a multipole radiofrequency tumour ablatograph with a pulse power of 200 W, a pulse frequency of 290 kHz and a final temperature of 90 °C. If the temperature rises above 90 °C, the ablatograph automatically reduces power so as to avoid current interruption owing to carbonisation.

The ablation electrode used was the conformable RFA electrode model WHK-3-8-4 (Wellfare Electronic Technological Company). It is a multipole cluster electrode with 12 thin curved monopolar subelectrodes extending in a circle from the central cannula (Figure 1a). The subelectrodes on each side of the circle (sides A and B) are controlled so that the operator can adjust the arrangement of the subelectrodes on one side of the circle independently of the other. For example, it is possible to have all of the subelectrodes on side A extended and on side B retracted, creating a half-circle (Figure 1b). When subelectrodes on both sides are fully extended, the transverse diameter (vertical dimension from the main

electrode to the end of the subelectrode) is approximately 4.0 cm. The diameter between both sides is approximately 8.0 cm.

Pin holes flanking the ends of the subelectrodes automatically inject isotonic saline solution at a speed of 2 ml min⁻¹ and this can be controlled so that the saline is dispensed simultaneously on sides A and B, or on only one side at a time. About 75% of the most proximal region relative to the main electrode of each subelectrode is coated with semi-insulating materials, which reduces conductivity by 70%.

Results were measured using a digital display slide gauge (Guilin Measuring Equipment Factory, Guilin, Guangxi, China). The most common resolution is 0.01 mm, and the tolerance is ± 0.03 mm per 150 mm.

Experimental method

The liver is bound by a connective tissue capsule that extends into highly branched septae and contains additional perivascular connective tissue. For all experiments, three fresh ox livers were used and four sites in each liver were selected for ablation. The ox livers were placed on a rectangular plastic container (100×80×80 cm), secured at one end by an *in vitro* plate electrode, and about two-thirds of the liver was covered in physiological saline. Subelectrode data located close to the connective tissues as well as the intrahepatic vessels and duct system were excluded from the study. In the connective tissue, the heat field pattern and heat transfer were distinct from other parts of the liver. The saline passing through the intrahepatic vessels and duct system carried some of the heat away.

Experiments were divided into six groups based on the six potential deployments of the electrodes. The main electrode was inserted into the ox liver at approximately 4 cm. The site was ablated according to the following protocol for each experimental group.

(a)

(b)

Figure 1. The conformable radiofrequency ablation electrode. (a) The electrode consists of the main electrode located in the central cannula, and multiple thin curved monopolar subelectrodes extending from the central cannula. The subelectrodes form two semicircles so that each side of the circle of subelectrodes can be manipulated independently of one another. (b) The subelectrodes on one side of the apparatus are spread out at full length and withdrawn on the other side, creating an asymmetrical shape.

Group I. The site was ablated for 15 min with the subelectrodes on side A fully extended and all subelectrodes on side B retracted. After that, the site was ablated for another 15 min with the subelectrodes on side B fully extended and all subelectrodes on side A retracted (symmetrical ablation).

Group II. The site was ablated for 15 min with the subelectrodes on side A fully extended. The electrodes on side B remained in a retracted arrangement.

Group III. The site was ablated for 15 min with the subelectrodes on side A remaining retracted. The electrodes on side B were fully extended.

Group IV. The site was ablated for 15 min with the subelectrodes on side A half extended and all subelectrodes on side B retracted. After that, the site was ablated for another 15 min with the subelectrodes on side B half extended and all subelectrodes on side A retracted.

Group V. The site was ablated for 15 min with the subelectrodes on side B fully extended and all subelectrodes on side A retracted. After that, the site was ablated for another 15 min with the subelectrodes on side A half extended and all subelectrodes on side B retracted.

Group VI. The site was ablated for 15 min with the subelectrodes on side A fully extended and all subelectrodes on side B retracted. After that, the site was ablated for another 15 min with the subelectrodes on side B half extended and all subelectrodes on side A retracted.

Statistical analysis

Data were presented as mean $\pm$ standard deviation. The baseline differences were compared using a *t*-test, and the differences on liver sides were compared using a paired test. Data were analysed using SPSS® v.15.0 (SPSS

Inc., Chicago, IL). A *p*-value of <0.05 was considered statistically significant.

Results

Symmetrical ablation

A total of 12 sites were ablated. However, some data were excluded from the analysis because the subelectrodes were close to connective tissues or close to the intrahepatic vessels and duct system in the liver. The total transverse diameter of the ablations for Group I (fully extended on both sides) was approximately 8.5 cm, and the vertical diameter was approximately 4 cm (Figure 2). The mean transverse diameter value for necrotic tissue in the region covered by the subelectrodes on side A was 4.07 ± 0.31 cm, which was similar to the transverse diameter for the necrotic tissue on side B (4.16 ± 0.18 cm; $p=0.682$), as seen in Table 1. The total transverse diameter of the ablations for Group IV (half extended on both sides) was approximately 6.5 cm, and the vertical diameter was approximately 3.2 cm. The mean transverse diameter value for necrotic tissue in the region covered by the subelectrodes on side A was 3.25 ± 0.10 cm, which was similar to the transverse diameter for the necrotic tissue on side B (3.23 ± 0.15 cm; $p=0.580$), as seen in Table 1. Therefore, the half-extended electrodes in Group IV also created a symmetrical ablation, but the area of ablation was reduced.

Asymmetrical ablation

Groups II, III, V and VI created asymmetrical ablation. Groups II and III were fully extended on side A and side B, respectively, but the electrodes were retracted on the other side. Both sides showed significant differences in transverse diameter in the ablation area (Table 1; $p<0.001$). In Group II (Figure 3), for example, the fully extended side generated a 4.04 ± 0.16 cm diameter

Figure 2. Group I. The subelectrodes on both sides A and B are fully extended. The total transverse ablation was approximately 8.5 cm. (a) On the incisal surface, the transverse diameter for necrotic tissue in the area of the liver covered by subelectrodes on side A was approximately 4.3 cm, which was similar to (b) the necrosis pattern on side B (approximately 4.2 cm).

Table 1. Transverse diameter in distribution area of subelectrodes for the six potential electrode deployment patterns

Group	Number of sites ^a	Subelectrode		Transverse diameter in distribution area of the subelectrode (cm)		<i>p</i> -value
		Side A	Side B	Side A	Side B	
I	9	Fully extended	Fully extended	4.07 ± 0.31	4.16 ± 0.18	0.682
II	11	Fully extended	Retracted	4.04 ± 0.16	1.59 ± 0.13	<0.0001 ^b
III	11	Retracted	Fully extended	1.68 ± 0.11	4.06 ± 0.23	<0.0001 ^b
IV	11	Half extended	Half extended	3.25 ± 0.10	3.23 ± 0.15	0.5801
V	10	Half extended	Fully extended	3.18 ± 0.11	4.13 ± 0.25	<0.0001 ^b
VI	11	Fully extended	Half extended	4.28 ± 0.06	3.15 ± 0.35	<0.0001 ^b

^aThe experiment was conducted in 12 separate sites, but some data were excluded from the analysis because of the close proximity of the subelectrodes to either connective tissues or the intrahepatic vessels and duct system.

^bSignificantly different from side A.

ablation area but the fully retracted side reduced the ablation area transverse diameter to approximately 1.59 ± 0.13 cm (Table 1). Groups V and VI were half extended on side A and side B, respectively, but the electrodes were fully extended on the other side. Both sides showed significant differences in transverse diameter in the ablation area (Table 1; $p < 0.001$). In Group VI (Figure 4), for example, the fully extended side generated a 4.28 ± 0.06 cm diameter of ablation area but the half-extended side reduced the ablation area transverse diameter to approximately 3.15 ± 0.35 cm (Table 1).

Discussion

RFA is an important strategy for treating patients with non-resectable hepatocellular carcinomas, as it reduces tumour size and prevents growth. Standard RFA uses symmetrically shaped electrodes, resulting in both ablation and symmetrical necrosis. However, most tumours are irregularly shaped, and overcoming this usually requires multiple treatments; this results in an increased number of both liver punctures and increased X-ray exposure owing to CT scanning used for guiding electrode positioning [1, 7, 8]. A standardised protocol is necessary to treat individual tumours with RFA based on

their size, shape and specific location [e.g. distance from nearby major organ(s)] [9].

Some parameters that affect the ablation pattern include the radiofrequency generator, the ablation electrode performance and tissue environment characteristics [10–12]. Necrosis generated by RFA results from thermal degradation caused by the cross-collision of electric ions in a shock current. Adjustment of the radiofrequency current density can change the heat generation and consequently the scope and shape of the resulting necrotic pattern. The simplest way to change the current radiofrequency density is to change the electrode distribution.

This study investigated whether the newly designed WHK-3-8-4 conformable RFA electrode could produce an asymmetrical ablation pattern in *ex vivo* ox liver. As described previously, this electrode is designed so that two groups of subelectrodes arranged on either side of a circle (six subelectrodes in each group) can be either extended or withdrawn to form asymmetrical shapes. We found that full extension of the subelectrodes on each side of the circle resulted in a symmetrical pattern of ablated tissue (mean values for side A = 4.07 ± 0.31 cm and side B = 4.16 ± 0.18 cm; $p = 0.682$). When the electrodes were extended on only one side of the circle, the resulting pattern of ablated tissue was asymmetrical (mean value for side A = 4.04 ± 0.16 cm and side

(a)

(b)

Figure 3. Group II. The subelectrode on side A was fully extended but the electrode on side B was fully retracted. (a) On the incised surface, the transverse diameter for necrotic tissue in the area of the liver covered by the subelectrodes on side A was approximately 4.0 cm, which was greater than (b) the transverse diameter of necrosis for side B (approximately 1.6 cm).

Figure 4. Group VI. The subelectrode on side A was fully extended but the electrode on side B was half extended. (a) On the incisal surface, the transverse diameter for necrotic tissue in the area of the liver covered by the subelectrodes on side A was approximately 4.2 cm, which was greater than (b) the transverse diameter of necrosis for side B (approximately 3.0 cm).

$B=1.59 \pm 0.13$ cm; $p=0.0001$). In the event of a tumour located close to critical organs (such as the gallbladder), asymmetrical necrosis could be achieved by a single puncture (*i.e.* single-pin puncture asymmetrical ablation), which is smaller close to the critical area and larger on the opposite side. This newly designed electrode covers the lesion using a single ablation without redundant punctures to the liver and increased X-ray exposure as a result of CT scanning.

Although in the asymmetrical experiments the necrotic tissue distribution was smaller on side B than on side A, side B still had necrotic tissue. The reason for this may be that both the main electrode and the side A subelectrodes had an impact on the ablation thermal field. Although three-quarters of the proximal ends of the main electrode and the subelectrodes are coated with semi-insulating materials, this material reduces conductivity by only 70%. Another possibility is that the injected physiological saline solution infiltrated tissue on side B, increasing the current density.

Our study had several notable limitations. First, as this was an *ex vivo* study, the results might be different from other *in vivo* studies in terms of effects on blood flow and the extent of ablation. Although there are differences in the proportion of proteins and water between normal and abnormal (*e.g.* cancerous) hepatic parenchymal pathology, these differences were not fully investigated. In addition, the size and shape of the ablation electrodes following extension require improvement.

It is clinically important that RFA improves disease outcome with few procedure-related complications. New radiofrequency technologies are needed to minimise multiple liver punctures and possible complications. Our findings indicate that the WHK-3-8-4 conformable electrode can produce asymmetrical necrosis. The size and shape of the ablation can be altered by both withdrawing and extending the subelectrodes to different lengths. However, additional experiments are required to assess whether this electrode can more efficiently decrease tumour size and prevent growth of

tumours *in vivo*, and therefore minimise the requirement for multiple treatments.

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