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THE EFFECT OF MONOPOLAR ELECTROCAUTERY ON THE SMALL INTESTINE OF THE RAT

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A b s t r a c t

In order to minimise the risk of undesirable side effects of monopolar electrocautery (MPEC), experiments were carried out to test the effects of MPEC on the small intestine of rats; the supply artery of the intestine was subject to electrocautery at various distances from the intestine wall. We evaluated the resulting adhesions in the peritoneal cavity and the effect of MPEC on the serosa, muscle and mucosa layers of the small intestine. We found that the number of adhesions increased with time after MPEC application and that the adhesions arose sooner when MPEC was applied nearer to the intestine. The duration of MPEC also had a strong influence on injury to the serosa. After MPEC application lasting 5 sec, the serosa was always injured. After electrocautery at greater distances from the intestine, injury to the muscle layer was visibly lower. Injury to the mucosa decreased with an increasing distance from the cautery site from the intestine.

K e y w o r d s

Laparoscopy, Electrocautery; Intestine

INTRODUCTION

The number of laparoscopic surgery interventions has been steadily growing and the spectrum of mini-invasive techniques utilised in surgery has been expanding in recent years *(4, 10, 12, 16*).

As early as 1987, convincing biophysical and biochemical evidence was brought by Kurt Semm*,* one of the pioneers of laparoscopic surgery techniques, suggesting that high-frequency currents cannot be considered completely safe if used in the closed abdominal cavity. Some authors have recommended that electrocautery in certain anatomic regions should be replaced by other techniques, such as thermocoagulation in Calot's triangle (*Jurka,* 1993). In spite of this, monopolar electrocautery (MPEC) has remained the most frequently used coagulation method in laparoscopic surgery and has been used by approximately 95% of the operating surgeons (*3, 9). Zucker (15)* has described the safe use of electrosurgery without any complications in over 800 laparoscopic interventions including acute cholecystitis.

In 1992, *Park* (*7*) described a stenosis of bile ducts after laparoscopic cholecystectomy performed with the use of electrocautery. Problems with monopolar electrosurgery may be caused by unrecognised „stray currents“ *(5, 11)*. These problems associated with the use of electrosurgery in laparoscopic applications have not yet been solved completely, by either doctors or engineers *(1, 2, 4, 6, 13, 14)*.

On the basis of the above-mentioned data in the literature and our own experience, we carried out experiments with the aim of investigating the side effects of monopolar electrocautery in laparoscopic surgery and minimising its undesirable effects.

MATERIALS AND METHODS

The experimental work was first prepared theoretically by studying data in the relevant literature; then the plan of experiments was submitted to the Committee for Ethics of Medical Experiments at Facultyy of Medicine, Masaryk University in Brno for approval. The Committee approved the experimental study in its session on June 22, 1993, as file no. 63/93.

The experiments were performed on healthy rats described as "laboratory rat or "white rat" (*Rattus norvegicus*). The weights of individual rats ranged from 150g to 540g, with a mean value of 328 g. A total of 103 animals were included. The experiments were performed in the experimental room of the First Department of Surgery, St. Anne's Teaching Hospital, Masaryk University in Brno. Surgical instruments used in the experiments were, whenever possible, the instruments commonly used in plastic surgery in order to minimise possible secondary injury to tissues and also with respect to the size of the inner organs of the experimental animals.

The rats were operated on the experimental surgery table, fixed on a pad, lying on their backs with upper and lower extremities stretched out. The surgery was performed under general anaesthesia and aseptic conditions.

In the experiment, the effect of monopolar electrocautery was tested by applying it on mesenteric arteries at various distances from the abdominal wall. Before the application of monopolar electrocautery, the vessel was constricted with a metal clip in order to simulate the conditions that are usual during laparoscopic surgery. In practice, metal endoclips are used to close large diameter vessels; the clip is electrically conductive. Minor bleeding, occurring in the vicinity of the endoclip, is frequently controlled by electrocautery. During this, accidental contact of the active electrode with the endoclip cannot be ruled out.

Monopolar high-frequency surgery can induce harmful stray currents that, under certain conditions, can act at sites distant from the region of the envisaged effects. Secondary undesirable effects often appear at sites where the tissues are compressed or narrowed and also at sites of inadvertent contacts *(2,9)*. Compression of tissues during the preparation or extension with ensuing narrowing can both occur during laparoscopic interventions. In addition, the technique of connecting the active monopolar electrode with the jaws of preparation tongs is often used for electrocautery.

The purpose of the experiment was to test the effects of monopolar electrocautery under special conditions. The rat intestine was selected as the test object because of its easy accessibility. We ensured that the metal clip was applied to an artery, supplying a selected segment of the small intestine and having a diameter of 1 mm, as found by calibration.

After narcotising the animal in the experimental operating room, the upper-medial laparotomy was performed under aseptic conditions. Small intestine loops of the animal were disengaged into the operation wound. A supply artery with a diameter of 1 mm was selected in the arterial arcades of the mesentery. The artery was constricted with a metal clip placed at a distance of 1 cm from the intestinal wall. Then the experimental procedure followed: monopolar electrocautery was applied to one of three defined sites (D, E, F) of the chosen mesenteric artery. Site D was in the middle of the distance between the metal clip and the small intestine wall. Its distances from both the clip and the small intestine wall thus amounted to 0.5 cm. Site E was on the metal clip closing the supplying mesenteric artery. Site F was at a distance of 0.5 cm from the metal clip in the centripetal direction.

After closing the abdominal cavity, samples for histological examination were taken from animals killed at various, pre-set intervals. The histological samples were taken from zones of presumed histological changes caused by the application of monopolar electrocautery. Zone B was on the small intestine at the site of the respective mesenteric supply artery. Zones A and C were on the opposite ends of zone B. The samples from zones A, B and C were examined histologically for possible changes in the serosa, muscle and mucosa layers.

The results were statistically analysed by Fisher's exact test, using the software CSS: STATISTICA, version 3.1 of 1992, company manual of StatSoft Tulsa OK 74104, U.S.A., and presented in the form of 2 x 2 tables.

RESULTS

A total of 103 operated experimental animals were included in the experiment. The results obtained were quantified and are shown in *Table1*. They were reprocessed and aggregated for statistical evaluation and are presented in *Table 2*.

After MPEC, the number of adhesions increased in the course of time, the increase being highly significant (*Tables 3 and 4*).

The adhesions in site D appeared earlier than in site E, F. After electrocautery, adhesions appeared only around the 30th day at site E and F while, at site D, they appeared approximately 10 days earlier and, in two observations, before day 14. The differences were statistically highly significant ($P < 0.0001$) (*Tables 5 and 6.).*

The difference between the effects of different durations of MPEC on the intestine serosa was highly significant. After a 5-second application at site D, the serosa was always injured even in peripheral regions while after MPEC applied for 2 sec, the A and C zones were sometimes undamaged (*Table 7*).

The effect of duration of MPEC on the muscle layer was not statistically significant as far as injury in individual zones was concerned. However, the injury was less severe after MPEC was applied to site F, as compared with both D and E sites ($P < 0.05$) (*Table 8*).

The musoca was undamaged in zones A and C in almost all cases; therefore, there was no point in statistical evaluation. After electrocautery at sites D and F or E and F, the differences were statistically significant ($P < 0.01$ or $P < 0.05$, respectively). The injury to the mucosa decreased with an increase in distance between the cautery site and the intestine. After cautery at site F (0.5 cm from the metal clip in the centripetal direction), the extent of injury was only slightly significant (*Tables 9 and 10*).

DISCUSSION

Living tissue in an electric field behaves as a special type of conductor. It is different from both metal conductors and electrolytes due to its macroscopic and

Table 1
The effect of monopolar electrocautery on the intestine

C	V 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	V 10
1	5	6	11	0	2	0	0	1	1	0
2	5	6	11	0	2	0	0	1	1	0
3	5	6	11	0	2	0	0	1	0	0
4	5	6	11	0	2	0	0	1	0	0
5	5	6	21	0	2	0	0	1	0	0
6	5	6	21	0	2	0	0	1	0	0
7	5	6	21	0	2	0	0	1	0	0
8	5	6	21	0	2	0	0	1	0	0
9	5	6	21	0	2	0	0	1	0	0
10	5	6	21	0	2	0	0	1	0	0
11	5	6	21	0	2	0	0	1	0	0
12	5	6	21	0	2	0	0	1	1	0
13	5	6	21	0	2	0	0	1	0	0
14	5	6	21	0	2	0	0	1	1	0
15	5	5	21	0	2	0	0	1	1	0
16	5	5	21	0	1	1	0	1	1	0
17	5	5	21	0	2	0	0	1	1	1
18	5	5	21	0	2	0	0	1	1	1
19	5	5	21	0	1	1	0	1	0	0
20	5	5	21	0	2	2	0	1	1	0
21	5	5	21	0	2	0	0	1	1	0
22	5	5	21	0	2	0	0	1	1	0
23	5	5	21	0	2	0	0	1	1	1
24	5	5	21	0	1	1	0	1	1	0
25	5	5	21	0	2	0	0	1	1	0
26	5	5	21	0	2	0	0	1	1	0
27	5	5	21	0	2	0	0	1	1	1
28	5	5	21	0	2	0	0	1	0	0
29	5	5	21	0	1	0	0	1	1	0
30	5	5	21	0	2	0	0	1	1	0
31	5	5	21	0	2	0	0	1	1	1
32	5	5	21	0	1	0	0	1	0	0
33	5	5	21	0	1	1	0	1	1	0
34	5	5	21	0	1	1	0	1	0	0
35	5	5	10	0	0	0	0	1	0	0
36	5	5	10	0	2	0	0	1	0	0
37	5	5	10	0	1	0	2	1	1	1
38	5	5	10	0	2	0	0	1	1	0
39	5	5	10	0	2	0	0	1	0	0
40	5	5	10	0	2	1	0	1	1	1
41	5	5	10	0	1	0	0	1	1	1
42	5	5	10	0	2	0	0	1	0	0
43	5	5	10	0	2	1	0	1	1	0
44	5	5	10	0	1	0	0	1	1	0
45	2	4	7	0	2	1	0	1	1	0
46	2	4	7	0	2	0	0	1	1	1
47	2	4	7	0	2	0	0	1	1	1
48	2	4	7	0	2	2	0	1	1	0
49	2	4	7	0	2	1	0	1	1	0
50	2	4	1	0	2	0	1	1	1	0
51	2	4	7	0	1	0	0	1	1	0
52	2	4	1	0	0	1	0	1	0	0

Table 1
The effect of monopolar electrocautery on the intestine (cont.)

C 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	V 10	V
53	2	4	7	0	2	2	0	1	1	0
54	2	4	7	1	0	1	0	1	1	0
55	2	4	14	0	0	0	0	1	0	0
56	2	4	14	0	2	0	0	1	0	0
57	2	4	14	0	2	0	0	1	1	0
58	2	4	14	0	1	0	0	1	0	0
59	2	4	14	0	2	0	0	1	0	0
60	2	4	14	1	2	1	1	1	1	1
61	2	4	29	0	1	2	0	1	0	1
62	2	4	29	0	1	1	0	1	1	1
63	2	4	29	0	1	0	0	1	0	0
64	2	4	29	1	1	0	0	1	1	0
65	2	4	29	1	0	0	0	0	0	0
66	2	4	30	1	2	0	0	0	0	0
67	2	4	30	1	2	0	0	1	1	1
68	2	4	30	1	1	0	0	1	1	1
69	2	4	30	1	2	0	0	1	1	0
70	2	4	30	1	2	0	0	1	0	0
71	2	4	30	1	2	2	0	1	1	1
72	2	4	30	0	1	0	0	1	1	0
73	0	0	14	0	0	0	0	1	0	0
74	0	0	14	0	0	0	0	0	0	0
75	0	0	14	0	0	0	0	1	0	0
76	5	6	31	0	2	0	0	1	0	0
77	5	6	31	0	2	0	0	1	0	0
78	5	6	31	0	2	0	0	1	0	0
79	5	6	42	1	2	0	0	1	0	0
80	5	6	42	1	2	0	0	1	1	0
81	5	6	42	1	2	0	0	1	0	0
82	5	6	42	1	2	0	0	1	0	0
83	5	6	42	0	2	0	0	1	0	0
84	5	6	42	1	2	1	0	1	1	0
85	5	6	42	1	2	0	0	1	0	0
86	5	6	42	0	0	0	0	1	1	1
87	5	6	42	0	2	0	0	1	0	0
88	5	6	42	1	2	0	0	1	0	0
89	5	6	42	1	2	0	0	1	0	0
90	5	6	42	1	2	0	0	1	0	0
91	5	6	42	1	2	1	0	1	1	0
92	5	6	42	0	2	0	0	1	0	0
93	5	4	20	1	2	1	0	1	1	0
94	5	4	20	1	2	0	0	1	1	0
95	5	4	20	1	2	0	0	1	1	1
96	5	4	2	0	1	0	0	1	1	1
97	5	4	20	1	2	0	0	1	1	1
98	5	4	20	1	2	0	0	1	0	1
99	5	4	20	1	2	2	0	1	1	1
100	5	4	20	1	2	0	0	1	1	0
101	5	4	20	1	2	0	0	1	1	1
102	5	4	20	0	2	0	0	1	1	0
103	5	4	20	1	2	1	0	1	1	0

Explanation to *Table 1*

C – Serial number of the experimental animal.

V1 – Duration of MPEC in seconds.

V2 – Site at which MPEC was applied was designated as follows:
4, side D; 5, site E; 6, site F.

V3 – Number of days after MPEC when samples were taken for histological examination.

V4 – Adhesions in the peritoneal cavity in the vicinity of MPEC application :
0 - no changes in the serosa in either A or C zone;
1 - adhesions observed at the time of sampling.

V5 – Alterations in the serosa found in zones A and C on histological examination of the sample (code numbers for zones: A=1, B=2, C=3). The results of histological examination in zones A and C were assessed according to the following key :
0 – no alterations in the serosa in either A or C;
1 – injury to the serosa either in A or C;
2 – injury to the serosa in both A and C.

V7 – Alterations in the mucosa found in zones A and C on histological examination of the sample were expressed as follows:
0 – no alternations in the musoca in either A or C;
1 – alternations in the mucosa in either A or C;
2 – alternations in the mucosa in both A and C.

V8 – Alternations in zone B of the serosa:
0 – no changes found;
1 – alternations present.

V9 – Alternations in zone B of the muscle:
0 – no changes found;
1 – alterations present.

V10 – Alterations in zone B of the mucosa:
0 – no changes found;
1 – alterations present.

Table 2
The effect of MPEC on the intestine related to the duration and site of application and the day of sample collection

PART A

D	Z	Time	Adhesions		Zones A + C								
					Serosa			Muscle			Mucosa		
			0	1	0	1	2	0	1	2	0	1	2
0	0	14	3	0	3	0	0	3	0	0	3	0	0
2	4	1	2	0	1	0	1	1	1	0	1	1	0
2	4	7	7	1	1	1	6	3	3	2	8	0	0
2	4	14	5	1	1	1	4	5	1	0	5	1	0
2	4	29	3	2	1	4	0	3	1	1	5	0	0
2	4	30	1	6	0	2	5	6	0	1	7	0	0
5	4	20	1	9	0	0	10	7	2	1	10	0	0
5	5	10	10	0	1	3	6	8	2	0	9	0	1
5	5	21	20	0	0	7	13	14	5	1	20	0	0
5	6	11	4	0	0	0	4	4	0	0	4	0	0
5	6	21	10	0	0	0	10	10	0	0	10	0	0
5	6	31	3	0	0	0	3	3	0	0	3	0	0
5	6	42	4	10	1	0	13	12	2	0	14	0	0

PART B

D	Z	Time	Zone B					
			Serosa		Muscle		Mucosa	
			0	1	0	1	0	1
0	0	14	1	2	3	0	3	0
2	4	1	0	2	1	1	2	0
2	4	7	0	8	0	8	6	2
2	4	14	0	6	4	2	5	1
2	4	29	1	4	3	2	3	2
2	4	30	1	6	2	5	4	3
5	4	20	0	10	1	9	5	5
5	5	10	0	10	4	6	7	3
5	5	21	0	20	4	16	15	5
5	6	11	0	4	3	1	4	0
5	6	21	0	10	8	2	10	0
5	6	31	0	3	3	0	3	0
5	6	42	0	14	10	4	13	1

Explanation to *Table 2*

D – Duration (in sec) of MPEC application; in the control group (T = 0), no MPEC was used and an endoclip was applied to the mesenteric artery.

Z – Site of MPEC application on the mesenteric artery: 0, not applied; 4, applied at site D; 5, applied at site E; 6, applied at site F.

Time (in days) – period between MPEC application and sampling for histological examination

Adhesions – presence or absence of adhesions in the mesentery region adjoining sites D, E and F: 0, no adhesions found; 1, adhesions present.

Zones A + C – the effect of MPCE applied to sites D, E or F on the serosa, muscle and mucosa of the small intestine found in zones A and C : 0, no alterations; 1, lesions either in zone A or C; 2, lesions in zones A and C.

Zone B – the effect of MPEC applied to sites D, E or F on the serosa, muscle and mucosa of the intestine found in zone B: 0, no alterations; 1, lesions present.

microscopic non-homogeneity *(2,4,12).* The electric current flowing through the tissues passes through the media of various chemical composition, viscosity and structure. These involve, for example, the cell membranes and cytoplasmic structures, intercellular media, etc. *(7).*

Each of these media is characterised by a specific conductance; the specific conductance of intercellular spaces and cell cytoplasm are similar, but the conductance of cell membranes is, on average, 106 to 108 times lower. The electric conductance of tissues is predominantly mediated by ions, i. e., electrolytically. The involvement of other mechanisms, such as electrophoretic conductance (i.e., motion of electrically charged colloid particles), electro-osmosis (i.e., motion of fluid) or protonation (i.e., direct transfer of hydrogen ions is much smaller. Unlike standard conductors, the ohmic resistance of tissues is not constant. Its value decreases during the flow of electric current. The electric resistance of tissues also depends on their functional state: a lack of oxygen results in increased resistance, which, at first, is reversible. The arrest of living processes results in a decrease in the conductance. When a high-frequency current of sufficient intensity passes through cell liquid from the active to the neutral electrode, heat generation is so rapid that steam generated within the cells breaks the cell membranes. This effect is generally used in surgery for incision or coagulation of tissues. Therefore, electric surgery units are equipped with high-frequency apparatus that permits the destruction of tissue cells.

Table 3

Adhesions at site D after application of monopolar electrocautery

Period of sample collection (days)	Adhesions in animals examined (n=28)	
	Absent	Present
1 to 14	14 50.000%	2 7.143%
29 to 30	4 14.286%	8 28.571%

P = 0.004800

Table 4

Adhesions at site F after application of monopolar electrocautery

Period of sample collection (days)	Adhesions in animals examined (n=31)	
	Absent	Present
11 to 21	14 45.161%	0 0.000%
31 to 42	7 22.581%	10 32.258%

P = 0.000438

Table 5

Adhesions at sites D and E at 20 to 31 days after monopolar electrocautery

Site	Adhesions in animals examined (n=42)	
	Absent	Present
D	5 11.905%	17 40.476%
E	20 47.619%	0 0.000%

P = 0.000000103

Table 6

Adhesions at sites D and F at 20 to 31 days after monopolar electrocautery

	Adhesions in animals examined (n=35)	
Site	Absent	Present
D	5 14.286%	17 48.571%
F	13 37.143%	0 0.000%

P = 0.000006

Table 7

The effect of MPEC duration at site D on zones A and C of the intestinal serosa

	Injury to the serosa (zones A and C) in animals examined (n=76)	
Duration of application	Damaged zones	Undamaged zones
2 sec	16 21.053%	40 52.632%
5 sec	0 0.000%	20 26.316%

P = 0.003846

Table 8

The effect of 2-second application of MPEC at sites D and F on the intestinal serosa

Site	Injury to the serosa in animals examined (= 82)	
	Undamaged	Damaged
D	16 19.512%	4 4.878%
E	60 73.171%	2 2.439%

P = 0.029021

Table 9

The effect of 2-second MPEC application at sites D and F on the intestinal mucosa

Site	Injury to the mucosa in animals examined (n=41)	
	Damaged	Undamaged
D	5 12.195%	5 12.195%
F	30 73.171%	1 2.439%

P = 0.001784

Table 10

The effect of 5-second MPEC application at sites E and F on the intestinal mucosa

	Injury to the mucosa in animals examined (n=61)	
Site	Undamaged	Damaged
E	22 36.066%	8 13.115%
F	30 49.180%	1 1.639%

P = 0.011288

As recently described, a number of different situations occur in surgery when undesirable secondary burns may appear during the use of electric current *(15).* But two physical principles are clear: firstly, the current flows through paths of lowest resistance and, secondly, if the current is strong enough, burns appear. Providing the current is high and the corresponding voltage low, the current may be suppressed or flow through other paths with lower resistance *(8,9).*

In our experimental work, we showed that the number of adhesions in the mesenteric region adjoining the site of MPEC application increased with the duration of MPEC application. When MPEC was applied to the mesenteric artery nearer to the intestine, the adhesions developed sooner. When MPEC was applied to the mesenteric artery at site D for 5 sec, the serosa of the small intestine was always injured; when it was applied for only 2 sec, the peripheral zones were sometimes left intact. MPEC applied at more remote sites resulted in significantly less injury to the muscle layer or the small intestine of the experimental animal.

Injury to the mucosa decreased with an increasing distance of the cautery site from the intestine. The decrease was significant when the cautery was applied to site F (above the clip).

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VLIV MONOPOLÁRNÍ ELEKTROKOAGULACE NA TENKÉ STŘEVO U KRYSY

S o u h r n

Za účelem minimalizace rizika vedlejších nezádoucích efektů monopolární elektrokoagulace byl připraven experiment testující vliv monopolární elektrokoagulace na tenké střevo u krysy: Na výživnou tepnu střeva bylo působeno elektrokauterem v různých vzdálenostech od střeva. Hodnotili jsme vzniklé srůsty v peritoneální dutině a vliv monopolární elektrokoagulace na serozu, tunicu muscularis a mukozu tenkého střeva. Zjistili jsme, že množství srůstů stoupá v závislosti na času po monopolární elektrokoagulaci a že srůsty vznikaly dříve, pokud byla elektrokoagulace použita blíž střevu. Délka monopolární elektrokoagulace měla také velký vliv na poškození serozy: Po aplikaci monopolární elektrokoagulace v délce 5s byla seroza vždy poškozena. Po působení elektrokauteru ve větší vzdálenosti od střeva bylo poškození svalové vrstvy střeva signifikantně výrazně menší. Poškození sliznice střeva klesá s rostoucí vzdáleností parametru pálení od střeva. Významný pokles nastává při pálení v parametru F (nad svorkou).

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