Gynecol Surg (2010) 7:441–446
DOI 10.1007/s10397-010-0582-3

ORIGINAL ARTICLE

Histological quantification of the tissue damage caused by PlasmaJet™ coagulator

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Received: 26 January 2010 / Accepted: 27 March 2010 / Published online: 20 April 2010

Abstract The purpose of this study was to evaluate tissue damage caused by the PlasmaJet™ coagulator in the uterus, ovary, and fallopian tube at different power settings in vitro and then to examine the damage caused in vivo. In vitro evaluation included prospective recruitment of six subjects undergoing hysterectomy with or without salpingo-oophorectomy. Tissue damage was evaluated histologically for power levels at 10%, 15%, and 20%, and for duration of 2 and 5 s at a clinically acceptable distance of 0.5 to 1 cm between the tip of probe and tissue. In vivo evaluation included 15 subjects undergoing hysterectomy with or without salpingo-oophorectomy. The most suitable power setting and duration of diathermy was decided from in vitro examination and applied on in vivo setting. Tissue damage was evaluated histologically. There was no significant difference seen in the depth and width of tissue damage in the in vitro specimens at different low power levels and duration of diathermy ($P>0.05$). A setting of 20% power and duration of 5 s of diathermy was used therefore for in vivo setting. Mean ± SD depth (millimetres) of tissue damage in uterus, ovary, and fallopian tube were 0.63±0.19, 0.61±0.14, and 0.63±0.18, respectively. Mean ± SD width (millimetres) of tissue damage in uterus, ovary, and fallopian tube were 4.66±0.05, 4.05±0.61, and 4.51±0.77, respectively. Irrespective of tissue type, the average depth and width of tissue damage with application of Plasmajet™ coagulator for 5 s at low power is 0.62 and 4.24 mm, respectively. It therefore appears to be a safe method of coagulation in vitro and in vivo at 20% power on gynaecological tissues.

Keywords Coagulator · Endoscopy · Tissue damage · PlasmaJet

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Background

The PlasmaJet™ coagulator is a new technology using neutral pure argon plasma to achieve coagulation [1]. If enough heat is added into a gas, atoms and molecules are ionised and form plasma, which is also called the fourth state of matter. When electrical energy is applied, the gas dissociates completely to form plasma which has equal number of positive and negative ions making it electrically neutral. In the PlasmaJet™ system, a low flow of argon gas is concentrated into a small space within the hand piece and excited by a low-DC voltage applied between internal bipolar electrodes [1]. The resulting argon plasma is a mixture of high energy argon ions and electrons that emerge from the tip of the hand piece in a precise jet stream. An important property of the plasma stream is that, since it contains an equal number of positively charged ions and electrons, the resulting plasma jet is electrically neutral [1]. The argon plasma emitted from the PlasmaJet™ hand piece is short-lived and gives up its energy readily in three forms; light, heat, and kinetic energy. The light illuminates the surgical field; thermal energy heats the tissues to cause coagulation forming a multilayer eschar, and kinetic energy assists in clearing any liquid or debris from the surface of the tissue [1]. A closer examination of the histology of

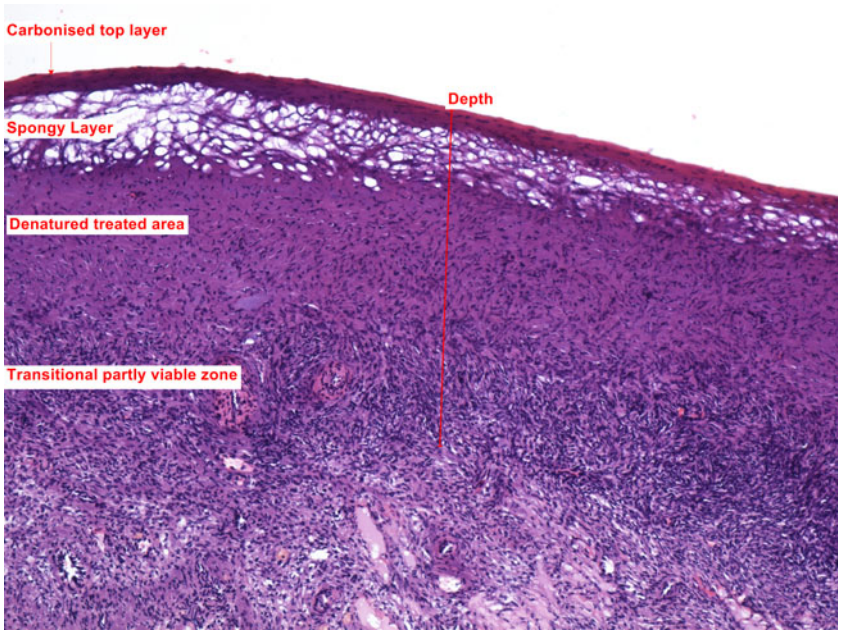

Fig. 1 Haematoxylin–eosin-stained section of ovarian tissue showing the depth of the treated area as measured from the uppermost layer of the vaporised tissue on the surface down to the deepest point within the tissue where viable tissue was identified

tissue after exposure to the PlasmaJet™ reveals three zones that comprise a thin flexible layer. On the tissue surface, there is usually a very thin (5–15 μm) carbonised layer, beneath which is an intermediate spongy necrotic layer of up to 0.3 mm in depth and a deeper more compact necrotic layer of up to approximately 1.6 mm in depth [2]. The very low gas flow used in the PlasmaJet™ system—typically, about 0.2–0.4 l/min is about a tenth of that used in the argon beam coagulator. As a result, the system is safe to use in laparoscopic surgery; there is no risk of over-inflation of the pneumoperitoneum or of a gas embolism [1].

Six studies have been conducted so far looking at the efficacy of PlasmaJet™ coagulator by evaluating the intra-operative haemostasis achieved and post-operative drain output from the operated site [3–8]. Four of these studies used PlasmaJet™ for large surface haemostasis during abdominoplasty [3–6]; one study used it for large surface coagulation in spinal, hip and knee surgery [7], and one study used it on large pleuritic surface during thoracic surgery [8]. All of them have reported that PlasmaJet™ was a safe, effective coagulator with significant reduction in post-operative drainage. One study has evaluated the feasibility

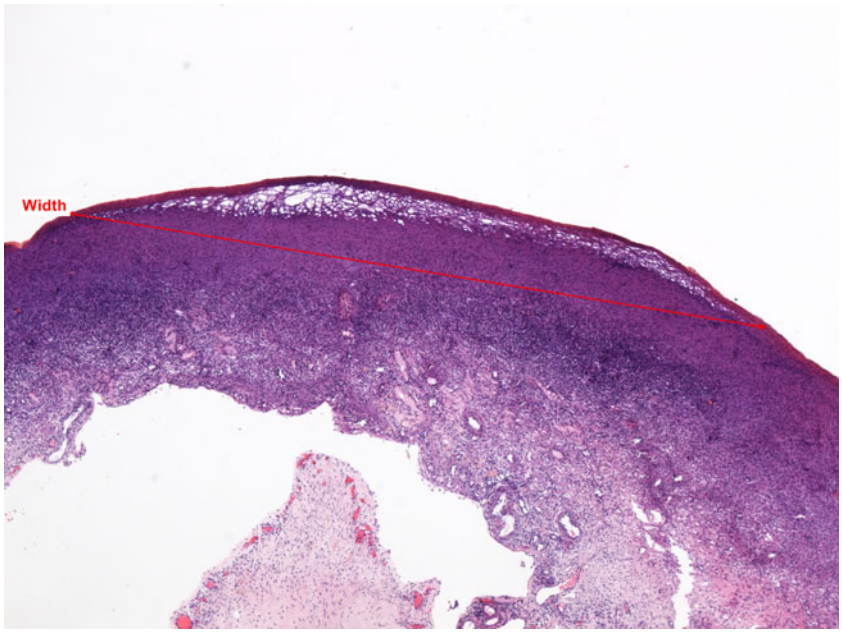

Fig. 2 Haematoxylin–eosin-stained section of ovarian tissue showing the width of the treated area as measured from the point joining viable tissue across the treated area laterally to the other end joining viable tissue

Table 1 Mean ± SD depth and width (lateral spread) of tissue damage caused by PlasmaJet™ coagulator in the uterine tissue in vitro

Power level	2s		5s	
	Depth (mm)	Width (mm)	Depth (mm)	Width (mm)
10%	0.48±0.16	4.45±0.82	0.52±0.18	5.01±0.69
15%	0.44±0.14	4.25±0.62	0.50±0.13	4.56±0.66
20%	0.46±0.14	4.05±0.54	0.51±0.11	4.82±0.76

and efficacy of PlasmaJet™ in the laparoscopic treatment of endometriosis by either vapourising or resecting the endometriotic spots and taking a biopsy from the base of the resected endometriotic lesion. They found the device multifunctional enabling vaporisation, coagulation, and cutting with minimal thermal spread [9].

Although the technique of PlasmaJet™ appears safe and novel with encouraging reports on effective haemostasis and post-operative recovery, there is no available data on the extent of tissue damage caused in human tissue. The objective of this study was therefore to evaluate the tissue damage caused by PlasmaJet™ coagulator at a low power setting in gynaecology, both in vitro and in vivo. The aim was to quantify the depth and width of tissue damage caused histologically such that its safety is ensured in future clinical use and also to assist future research.

Methods

Women undergoing elective hysterectomy with or without salpingo-oophorectomy for benign indications were prospectively recruited into the study. The initial part of the study involved histological evaluation of tissue damage caused by PlasmaJet™ when used in vitro at different low power settings and duration of application, at a clinically acceptable distance of 0.5 to 1 cm from the surface of the tissue. A suitable power and duration of application would be determined based on this part of the study for in vivo use. The study was given ethical approval by the Nottingham Research Ethics Committee, UK.

In vitro study On the first two specimens, PlasmaJet™ was used at 10% power for duration of 2 and 5 s at a distance of 0.5 to 1 cm. On the next two specimens, PlasmaJet™ was used at 15% power for duration of 2 and 5 s at a distance of 0.5 to 1 cm. On the last two specimens, PlasmaJet™ was used at 20% power for duration of 2 and 5 s at a distance of 0.5 and 1 cm.

In vivo study A suitable power level and duration of application was chosen based on the findings of in vitro evaluation. Plasmajet™ coagulator was used on the tissues within 15 min of clamping the uterine artery.

Tissue damage was quantified by measuring the width and depth of damage in millimetres.

Laboratory evaluation of the specimens

Specimens for histological analysis were transported in formalin to the laboratory on the same day of operation and histological analysis performed by three of the authors (SD, KA and AH). The treated area was sampled in its entirety with a rim of surrounding unaffected tissue. The aim was to bisect the diathermised area in the middle and embed the cut surface facedown. In some cases, either because of the size of the affected area or for technical reasons, there was a need to divide the treated area into three slices. A detailed list of all blocks and corresponding colour was kept for each case. All blocks were examined throughout the thickness of the sampled tissue with a distance of 200 u in between each section.

Using haematoxylin and eosin-stained sections, the areas in question were measured using microscope graticule. For each sample, the depth and width of the treated area was calculated. The depth of the treated area was measured from the uppermost layer of the vaporised tissue on the surface down to the deepest point within the tissue where viable tissue was identified (Fig. 1). The width of the treated area was measured from the point joining viable tissue across the treated area laterally to the other end joining viable tissue (Fig. 2). The thickness of the affected area was calculated by

Table 2 Mean ± SD depth and width (lateral spread) of tissue damage caused by PlasmaJet™ coagulator in the ovarian tissue in vitro

Power level	2s		5s	
	Depth (mm)	Width (mm)	Depth (mm)	Width (mm)
10%	0.52±0.16	5.15±0.72	0.59±0.19	5.10±0.69
15%	0.54±0.14	4.35±0.82	0.49±0.14	4.86±0.76
20%	0.48±0.18	4.10±0.56	0.54±0.16	4.50±0.66

Table 3 Mean ± SD depth and width (lateral spread) of tissue damage caused by PlasmaJet™ coagulator in the fallopian tube in vitro

Power level	2s		5s	
	Depth (mm)	Width (mm)	Depth (mm)	Width (mm)
10%	0.49±0.13	5.45±0.78	0.52±0.15	5.25±0.79
15%	0.50±0.15	4.65±0.72	0.45±0.12	4.96±0.70
20%	0.49±0.18	4.90±0.55	0.48±0.09	4.80±0.56

counting the number of sections that showed the diathermy effect multiplied by the distance between sections (200 u). The maximum measurement for each dimension was included for final assessment and comparison.

Statistical analysis

Statistical analysis was undertaken using the Statistical Package for the Social Sciences (SPSS, version 16.0, Chicago, IL). The distribution of the data was checked using normal probability plots. The mean and standard deviation (±SD) are given for normally distributed data and the median and range for non-parametric data. One-way analysis of variance (one-way ANOVA) was used to examine for differences in the mean depth and width of tissue damage when treated at different power levels and for different duration of time. A P value of <0.05 was considered to be statistically significant.

Findings

Six subjects were recruited for the in vitro evaluation of PlasmaJet™ coagulator. The mean ± SD age was 48.23± 3.03 years. All six subjects had subtotal hysterectomy with three undergoing bilateral oophorectomy, thus giving six uteri, six normal-appearing ovaries along with six fallopian tubes for histological evaluation. On the first two specimens, PlasmaJet™ was used at 10% power for duration of 2 and 5 s at a distance of 0.5 to 1 cm. On the next two specimens, PlasmaJet™ was used at 15% power for duration of 2 and 5 s at a distance of 0.5 to 1 cm. On the last two specimens, PlasmaJet™ was used at 20% power for duration of 2 and 5 s at a distance of 0.5 and 1 cm.

The mean ± SD depth and width of tissue damage in the uterus at power levels of 10%, 15%, and 20% for duration of 2 and 5 s is shown in Table 1. There was no significant difference seen in the depth and width of tissue damage when treated with PlasmaJet at different power levels (P> 0.05) and for different time durations (P>0.05), as tested using one-way ANOVA.

The mean ± SD depth and width of tissue damage in the ovaries at power levels of 10%, 15%, and 20% for duration of 2 and 5 s is shown in Table 2. There was no significant difference seen in the depth and width of tissue damage when treated with PlasmaJet at different power levels (P> 0.05) and for different time durations (P>0.05), as tested using one-way ANOVA.

The mean ± SD depth and width of tissue damage in the fallopian tube at power levels of 10%, 15% and 20% for duration of 2 and 5 s is shown in Table 3. There was no significant difference seen in the depth and width of tissue damage when treated with PlasmaJet™ at different power levels (P>0.05) and for different time durations (P>0.05), as tested using one-way ANOVA. Also, there appeared to be no significant difference in the depth and width of tissue damage between tissue types of uterus, ovary and fallopian tube (P>0.05).

For the in vivo analysis, we chose to study PlasmaJet™ at a power level of 20% to be tested for a duration of 5 s as there was no significant difference seen in in vitro tissue damage at different power levels and different duration of application. Fifteen subjects with an average age of 49.22 years were prospectively recruited. Ten subjects had subtotal hysterectomy, and five had total abdominal hysterectomy with bilateral salpingo-oophorectomy. Fifteen uteri, ten ovaries and ten fallopian tubes were histologically analysed for the tissue effect of PlasmaJet™. PlasmaJet™ coagulator was used on the tissues within 15 min of de-vascularisation of the uterus. Mean ± SD depth and width of tissue damage in uterus, ovary and fallopian tube are shown in Table 4. On comparing the means using one-way ANOVA, there was no significant difference seen in the width and depth of damage between tissues (P>0.05).

Table 4 Mean ± SD depth and width of tissue damage caused by PlasmaJet™ coagulator in vivo

	Depth (mm) mean ± SD	Width (mm) mean ± SD
Uterus (n=15)	0.63±0.19	4.66±0.05
Ovary (n=10)	0.61±0.14	4.05±0.61
Fallopian tube (n=10)	0.63±0.18	4.51±0.77

Conclusion

This is the first study quantifying histologically the tissue damage caused by PlasmaJet™ in gynaecology. The in vitro part of the study was designed to ensure safety when evaluating PlasmaJet™ in vivo. The average depth of tissue damage with a maximum duration of 5 s and a minimum distance from the tissue of 0.5 cm in vitro was 0.49 mm as compared with 0.62 mm in vivo. The average width of tissue damage in vitro was 4.66 mm as compared with 4.24 mm in vivo. The marginal increase in the depth of tissue damage seen in vivo as compared with in vitro might be due to the difference in vascularisation of the tissues, as in vitro the tissues were de-vascularised for a longer duration as compared with in vivo which was treated within 15 min of clamping the uterine artery pedicle. This finding would be of value and requires further consideration when designing future trials.

The histological evaluation of the depth and width of tissue damage is a more scientific method of assessment as compared with examining the visual effect of tissue damage. This information becomes more relevant when using PlasmaJet™ close to important anatomical structures and also when ablating endometrial nodules and tumour debulking. The female ureter is closely related to the pelvic organs and therefore at a risk of damage during operative procedures in the pelvis. It is therefore important to understand the extent of tissue damage caused with different electrosurgical techniques in order to prevent inadvertent damage to important structures. The current histological data available on the use of PlasmaJet™ is on the liver, kidney, spleen and lungs of six dogs [2]. In this study, PlasmaJet™ was used at a high power of 100 W for duration of 1, 5, 10 and 30 s. They found that the maximum depth of tissue damage of about 2 mm was reached with 5 s of application and that this depth did not increase with prolonged application, but caused vaporisation of the tissue [2]. In our study with 5 s of application, we found the average depth of tissue damage was 0.49 mm in vitro and 0.63 mm in vivo. This difference in depth of tissue damage is likely to be due to lower power of 20% used in our study. Also, varying vascularisation of tissues could contribute to these differences. In our study, tissues such as uterus, ovary and fallopian tube were tested, whereas, in the Russian study, liver, spleen, kidney and lungs were tested. Future studies should therefore be designed to look at whether the effect of PlasmaJet is affected by different types of tissues, when controlling for the power and duration of application.

The New York group evaluated PlasmaJet™ in vitro on harvested tumour specimens of ovarian and peritoneal adenocarcinoma at high power levels of 70%, 75%, 85% and 90% for a duration of 2 and 4 s [10]. They found that greater power and tissue interaction time resulted in more tumour vaporisation whilst maintaining minimal lateral thermal damage [10].This work is not directly comparable to our study due to the differences in the power levels used and the tissue tested. However, it seems to appear that with higher power, the cutting effect caused due to vaporisation is more precise as the depth of vaporisation increases whilst maintaining the lateral spread. In contrast, with lower power levels as used in our study, whilst the depth of coagulation or tissue damage is minimal the lateral spread is more when compared with higher power levels.

In conclusion, this study has shown that irrespective of tissue type, the average depth and width of tissue damage with the application of PlasmaJet™ coagulator for 5 s at a low power of 20% is 0.62 and 4.24 mm, respectively. It therefore appears to be a safe method of coagulation at 20% power on gynaecological tissues. This implies an ideal safe source of energy for dealing with endometriotic deposits and adhesions. However, further research into different power settings at different duration of application is warranted in order to ensure its effective use in the treatment of deeper endometriotic nodules and tumour debulking procedures.

Acknowledgement The authors acknowledge Plasma Surgicals for sponsoring the trial.

Conflict of interest Money was received by the institution for the histological analysis of the tissue.

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