Argon plasma coagulation for successful treatment of early gastric cancer with intramucosal invasion

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Background: In recent years, there has been an increasing number of cases of early gastric cancer (T1, NX) with intramucosal invasion, which are untreated by surgical or endoscopic mucosal resection (EMR) because of their high risk. Currently, no adequate treatment is available for such patients.

Aim: The main objective of this study was to evaluate whether argon plasma coagulation (APC) is an effective and safe modality for treating early gastric cancer untreated by surgical resection or EMR.

Methods: The study group comprised 20 men and seven women diagnosed with gastric cancer with intramucosal invasion who were considered poor candidates for surgical resection or EMR due to risk factors such as severe cardiac failure or thrombocytopenia. Irradiation conditions for APC treatment were determined using swine gastric mucosa. We used an argon gas flow of 2 l/min at a power setting of 60 W and a maximum irradiation rate of 15 s/cm². The follow up period of the 27 patients ranged from 18 to 49 months (median 30 months).

Results: All lesions were irradiated easily, including areas anatomically difficult for EMR such as the gastric cardia or the posterior wall of the upper gastric body. In 26 of 27 patients (96%) there was no evidence of recurrence during the follow up period (median 30 months). One patient showed recurrence six months after treatment but was successfully retreated. No serious complications were found in any of the 27 patients but three patients (11%) experienced a feeling of abdominal fullness.

Interpretation: APC is a safe and effective modality for treatment of early gastric cancer with intramucosal invasion, untreated by surgical resection or EMR. However, further observations are necessary to determine the long term prognosis of patients undergoing this treatment.

METHODS
Ex vivo experiments

Standard APC equipment consisting of a high frequency generator (ICC 200), an automatically regulated argon source (APC 300), and a flexible APC probe (2.3 mm in diameter, 100 W maximum output, and 2.4 l/min maximum flow rate) (ERBE Elektromedizin, Tuebingen, Germany) was used in this study.

Ex vivo experiments were performed to determine the irradiation conditions for APC using swine gastric walls which were obtained within one hour of sacrifice. Gastric mucosa from the two swine were examined in this study. An acrylic plate with multiple square holes (1 cm each) was placed over the anterior wall of the gastric body, and irradiation was performed with the applicator (electrode) at a distance of 3–5 mm from the tissue. The argon gas flow rate was 2.0 l/min. The power of the high frequency currents was 20 W, 40 W, 60 W, 80 W, and 100 W while irradiation times were five seconds, 10 seconds, 15 seconds, and 20 seconds. Using the formula energy (J) = output power (W) × time (seconds), the energy density (J/cm²) tested in this experiment ranged from 100 J/cm² (20 W×five seconds) to 2000 J/cm² (100 W×20 seconds).

The irradiated swine gastric walls were fixed in 4% formalin solution. An incision was made in the centre of each 1 cm×1 cm square for histological examination.

Abbreviations: EMR, endoscopic mucosal resection; APC, argon plasma coagulation; EUS, endoscopic ultrasonography.
cm irradiation field, and the harvested gastric mucosal specimen was stained with haematoxylin and eosin and Elastica-van Gieson. Depth of coagulation was measured for five loci, 2 mm each, on the 10 mm incised face, and the mean of five measurements was calculated.

Patients
We enrolled 27 patients; 20 men and seven women, mean age 78 (SD 7) years, who had early gastric cancer with limited invasion to the mucosal layer. The histological diagnosis was well differentiated adenocarcinoma in all patients. We confirmed by endoscopic ultrasonography (EUS) that the tumour remained within the mucosal layer in all patients and that there were no lymph node metastases or distant metastases detectable by computed tomography or EUS. All patients were untreatable by either surgical resection or EMR because of high risk conditions such as severe cardiac failure or thrombocytopenia. Prior to APC treatment, all patients were given a full explanation of the procedure and written informed consent was obtained.

Treatment
Based on the results obtained using swine gastric mucosa, we developed irradiation parameters for APC to use for curative treatment of early gastric cancer. Prior to irradiation, the area around each cancer lesion to be cauterised was marked. Then, irradiation was performed in the manner determined by the ex vivo experiments; irradiation at 60 W for 15 seconds (900 J/cm²) which caused the surface to become dry and the tissue to begin to change from white to brown. Cauterisation was usually performed once, and additional cauterisation was only done when endoscopic observation at seven days after the initial treatment suggested possible residual tumour tissue.

RESULTS
Ex vivo experiments
We first performed an ex vivo experiment on swine gastric mucosa to set the irradiation conditions of APC for use in the treatment of early gastric cancer in humans. Figure 1 shows the macroscopic appearance of swine gastric mucosa irradiated by argon plasma coagulation (APC) under various conditions. The effect of APC was macroscopically studied on swine gastric samples at 20, 40, 60, 80, and 100 W, with pulse durations of 5, 10, 15, and 20 seconds. The mucosa exposed to a greater output power of high frequency current and/or for a longer pulse duration underwent more conspicuous colour change from white to brown.
Endoscopic appearance of early gastric cancers treated by APC

The gastric cancers of the 27 patients measured 14 (SD6) mm in diameter on average, with the largest being 35 mm. The macroscopic types were determined in accordance with the Gross Morphologic Classification of Early Gastric Cancer at Endoscopy: 11 patients had type IIc lesions (depressed type), five had type Ila lesions (elevated type), two had type Ila+Ilc lesions (mixed type), and one had a type lIlb lesion (flattened type).

Effect of APC in patients with gastric cancer

Table 1 summarises the results of APC treatment in 27 patients who underwent APC therapy at 60 W for 15 s/cm². Ten patients were not eligible for EMR as they were receiving anticoagulant therapy because of a history of severe myocardial infarction, four patients could not undergo EMR because of ulceration, and 13 patients were enrolled for APC treatment because of tumour recurrence after EMR. Twelve patients had lesions at the gastric cardia, the posterior wall of the upper gastric body, or at the lesser curvature on the antrum where adequate endoscopic access for EMR is generally difficult. Except for one patient, patients were treated only once, and the mean duration of the endoscopic procedure was 13.4 minutes. The one exception was a patient who underwent treatment three times at seven day intervals because the lesion was too large to treat at one sitting. Patients were followed up for 18–49 months (median 30 months). Recurrence occurred in only one patient (3.7%) at six months after treatment. In this patient, the cancer had invaded the oesophago-cardiac junction, and it was difficult to cauterise completely. However, cautious retreatment with APC was successful in complete eradication of the tumour and no recurrence was observed for 39 months.

There were minimal complications associated with APC treatment. Three patients complained of abdominal fullness which improved soon after completion of the treatment. No patient developed perforation, bleeding, abdominal pain, or other symptoms.

Representative cases

A case of early depressed gastric cancer type IIc: patient No 2 in table 1

The patient was a 70 year old man with local recurrence of gastric cancer after EMR of a lesion on the anterior wall of the antrum (fig 4A). He had been diagnosed as having progressive myelodysplastic syndrome and could not be treated surgically due to thrombocytopenia (20 000/ml). EMR was considered unsafe due to the risk of bleeding and scarring of the lesion. Therefore, the patient was treated with APC (fig 4B). One week after treatment, an ulcer with whitish fur was noted (fig 4C). A biopsy revealed no residual tumour tissue, and the patient showed no evidence of recurrence 24 months after treatment (fig 4D).

Another case of early depressed gastric cancer type IIc: patient No 12 in table 1

The patient was a 73 year old man with local recurrence of gastric cancer after EMR of a lesion on the posterior wall of the upper gastric body. EMR was attempted but the lesion was not lifted after submucosal injection of saline because of ulceration (fig 5A, B). The patient was not a suitable candidate for surgery because of a previous myocardial infarction, and therefore APC was performed. Endoscopy at three weeks after APC treatment (fig 5C) revealed scarring of the lesion, and biopsy showed no residual tumour tissue. After 28 months, the patient showed no evidence of recurrence.

DISCUSSION

In this study, we first performed in vivo experiments using swine gastric mucosal tissue in order to set the irradiation...
conditions for APC in human. These experiments demonstrated that irradiation at 60 W for 15 seconds (900 J/cm²) cauterised the whole mucosal layer but did not affect the deep submucosal layer (figs 2, 3). Therefore, this setting should be ideal for the treatment of intramucosal cancer. Under all output settings tested from 20 to 100 W, the depth of coagulation increased as irradiation time was prolonged and plateaued after 15 seconds. Thus the ex vivo experiment demonstrated that the depth of coagulation could easily be adjusted by changing the irradiation time and current output, suggesting that this technique is both safe and effective for human application.

However, there is a concern that the effect of APC observed in the ex vivo experiment would be somehow attenuated in vivo because in living tissue there is blood flow that may act as a heat sink, thereby decreasing the effectual temperature. In addition, as no in vivo study on chronological changes of coagulation depth after APC irradiation was carried out, it is difficult to assume that deeper damage would not become apparent within a few days after treatment.

With these concerns in mind, we carefully applied the APC technique for the treatment of patients with intramucosal gastric cancer who had no lymph node metastases (T1N0M0) and in whom tumour eradication would be curative. As a result, APC showed a very high efficacy (no recurrence in 26/27 patients) after a follow up period of 18–49 months (median 30 months). Moreover, it should be noted that such high efficacy was obtained even with the cancers in 12 of the 27 patients located at endoscopically difficult areas to access, the cardia or posterior wall of the gastric body, probably by virtue of tangential irradiation and uniform cauterisation over a wide area.

Although preliminary, we also performed APC treatment for six early gastric cancer patients with high risk conditions who had tumours invading the submucosal layer (data not shown). In this particular trial, irradiation was performed at 80 W for 15 seconds (1200 J/cm²) on the basis of the ex vivo experiments. The tumours were successfully eradicated in all patients but local recurrence was observed in one case. Therefore, this modality may be effective not only in cases of intramucosal cancer but also in cancers limited to the submucosal layer. However, a careful follow up study is needed to determine the long term prognosis of patients undergoing the treatment, particularly for the latter cases. With regard to complications, only a sense of abdominal fullness was experienced by some patients but was easily alleviated by intermittent suction or by continuous suction using a two channel endoscope. No severe complications, such as perforation, were observed, probably due to the fact that the depth of coagulation can be strictly adjusted by changing the irradiation time and power (fig 2).

APC treatment for gastric cancer has been previously reported by Wahab and colleagues. However, their cases were of advanced gastric cancer in whom surgery would have had neither a curative nor a palliative effect due to extensive tumour growth or metastases, and outcome of treatment was
Photodynamic therapy has also been used to treat early gastric cancer. Its superiority compared with APC treatment is based on the uptake of a photosensitising dye by target cells, which are damaged by reactive oxygen intermediates generated after irradiation with light that has a wavelength matching the dye absorption spectrum. Although there is selective toxicity for tumour cells and a very low incidence of serious complications, photodynamic therapy has several disadvantages such as cutaneous photosensitivity, a long stay in the hospital, and a high cost, which are not factors in APC treatment. In addition, microwave coagulation was also used for the treatment of gastric cancer by Tabuse and colleagues. However, they treated only three patients with early gastric cancer, the majority being treated for palliative relief of advanced gastric cancer, indicating that the efficacy of microwave coagulation for early gastric cancer is still unclear.

Thus APC has advantages over previous therapies in terms of tangential irradiation and inexpensive compact equipment.

**CONCLUSION**

We used APC in 27 patients for the treatment of early gastric cancer that was untreatable by either surgical resection or EMR. The procedure was safe and no patient developed serious complications. In all cases, tumour tissue was palliatively treated with shrinkage of tumour and alleviation of symptoms.

There are several other modalities for local treatment of gastric cancer. Nd:YAG laser therapy has been used widely in patients with gastric cancer that is untreatable by surgical resection or EMR. However, two of the disadvantages of the Nd:YAG laser are its inability to irradiate tangentially and its relative expense compared with APC treatment. Photodynamic therapy has also been used to treat early gastric cancer. Photodynamic therapy is based on the uptake of a photosensitising dye by target cells, which are damaged by reactive oxygen intermediates generated after irradiation with light that has a wavelength matching the dye absorption spectrum. Although there is selective toxicity for tumour cells and a very low incidence of serious complications, photodynamic therapy has several disadvantages such as cutaneous photosensitivity, a long stay in the hospital, and a high cost, which are not factors in APC treatment.

Table 1  Characteristics of the 27 patients with early gastric cancer enrolled for argon plasma coagulation treatment

<table>
<thead>
<tr>
<th>Type of cancer</th>
<th>Case No</th>
<th>Age (y)</th>
<th>Sex</th>
<th>Location*</th>
<th>Diameter (mm)</th>
<th>Prior treatment</th>
<th>Follow up period (months)</th>
<th>Recurrence</th>
<th>Complications</th>
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<tr>
<td>IIa: elevated type</td>
<td>83</td>
<td>F</td>
<td>Lower body, l</td>
<td>10</td>
<td>EMR</td>
<td>30</td>
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<td></td>
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<tr>
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<td>2</td>
<td>M</td>
<td>Cardia</td>
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<td>EMR</td>
<td>35</td>
<td>(-) (-) (-)</td>
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<tr>
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<td>3</td>
<td>M</td>
<td>Lower body, p</td>
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<td>EMR</td>
<td>32</td>
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<tr>
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<td>EMR</td>
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<td>(-) (-) (-)</td>
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<tr>
<td>IIb: flat type</td>
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</tr>
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<td>73</td>
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<td>Antrum, l</td>
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<tr>
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<td>M</td>
<td>Antrum, l</td>
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<td>(-)</td>
<td>25</td>
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<td>EMR</td>
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<td>(-) (-)</td>
<td></td>
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<td>87</td>
<td>M</td>
<td>Antrum, l</td>
<td>10</td>
<td>EMR</td>
<td>24</td>
<td>(-) (-)</td>
<td></td>
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<tr>
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<td>81</td>
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<td>Lower body, p</td>
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<td>(-)</td>
<td>21</td>
<td>(-) (-)</td>
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<td>M</td>
<td>Lower body, p</td>
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<td>(-)</td>
<td>35</td>
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</tr>
<tr>
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<td>M</td>
<td>Antrum, a</td>
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<td>(-)</td>
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<td>(-) (-)</td>
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<td>M</td>
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<td>EMR</td>
<td>29</td>
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<tr>
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<td>M</td>
<td>Lower body, p</td>
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<td>(-) (-)</td>
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<td>(-)</td>
<td>36</td>
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<td>Upper body, p</td>
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<td>Upper body, p</td>
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<td>(-)</td>
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<td>(-) (-)</td>
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<tr>
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<td>81</td>
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<td>EMR</td>
<td>30</td>
<td>(-) (-)</td>
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<td>EMR</td>
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<td>EMR</td>
<td>45</td>
<td>(+) Intermittent abdominal distension</td>
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<td>67</td>
<td>M</td>
<td>Mid body, g</td>
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<td>EMR</td>
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<td>(-) Intermittent abdominal distension</td>
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</table>

*Mean (SD) 78 (7) 14 (6) 30 (7)
†Type IIa: case 5, was treated three times.
EMR, endoscopic mucosal resection.

Figure 4  A case of early gastric cancer type IIc (depressed type): patient No 2 in table 1. Age/sex: 70 years/male. Location: antrum, anterior. Size: 10 mm in diameter. Type: IIc (depressed type); residual lesion of post endoscopic mucosal resection. Depth: intramucosal invasion. Pathology: well differentiated adenocarcinoma. Comorbid factors: myelodysplastic syndrome, cerebral infarction. (A) Before irradiation; (B) immediately after irradiation; (C) one week after irradiation; and (D) six months after irradiation.
Figure 5  Another case of early gastric cancer type IIc (depressed type): patient No 12 in table 1. Age/sex: 73 years/female. Location: upper body, posterior. Size: 18 mm in diameter. Type: IIc (depressed type) with ulcer formation. Depth: intramucosal invasion. Pathology: well differentiated adenocarcinoma. Comorbid factors: myocardial infarction, cerebral infarction (A, B) before irradiation; and (C) three weeks after irradiation.

completely eradicated and necrosis was observed, suggesting that APC may be used as a means of curative treatment for early gastric cancer without lymph node or distant metastases. However, follow up is necessary to evaluate the long term prognosis of patients undergoing this treatment.

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