A New Parameter for Assessing Postoperative Recovery of Physical Activity Using an Accelerometer

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Abstract

Purpose. While many retrospective and prospective observational studies have shown laparoscopic surgery to be less invasive than conventional open surgery, this issue has not been evaluated by objective parameters. Currently available clinical parameters, such as the day of first ambulation, the day food intake is commenced, and the length of postoperative hospital stay, are subjective. The purpose of this study was to investigate whether measuring postoperative physical activity with an accelerometer is a useful parameter for evaluating postoperative recovery after surgical stress.

Methods. The subjects included 20 patients who underwent laparoscopic partial gastrectomy (LPG group), 35 patients who underwent open distal gastrectomy (ODG group), and 20 patients who underwent open total gastrectomy (OTG group). The cumulative acceleration of voluntary movement, measured by an Active tracer AC-301 (ACT) accelerometer for 7 days postoperatively, was compared among these three groups.

Results. The cumulative acceleration of physical activity for 24 h was significantly better in the LPG group than in the ODG and OTG groups on each postoperative day. The recovery time, defined as the day that cumulative acceleration had recovered to more than 90% of the preoperative level, was significantly shorter in the LPG group (2.8 ± 0.9 days) than in the ODG (6.6 ± 2.1 days) and OTG (7.8 ± 1.2 days) groups.

Conclusion. These results showed that convalescence differed with the degree of surgical stress, and that measurement of the cumulative acceleration of voluntary movement by using an accelerometer could be a useful objective and quantitative parameter for evaluating postoperative recovery.

Key words Accelerometer · Physical activity · Postoperative recovery · Surgical stress · Laparoscopic surgery

Introduction

Although laparoscopic approaches to examine and treat gastrointestinal disease have been enthusiastically accepted as less invasive than conventional open surgical approaches, they have not been adequately evaluated using objective and quantitative parameters. To date, such clinical parameters as the day of ambulation, the day of initial food intake, the length of postoperative hospital stay, and the time it takes to rehabilitate to the preoperative social level, have been used to evaluate the degree of surgical stress. These parameters have shown laparoscopic procedures to be less invasive; however, they are not only dependent upon the physician's directions, but are also affected by both the patient and a variety of social conditions. Thus, they are prone to bias and a lack of objectivity.

Based on the view that laparoscopic surgery is minimally invasive, and followed by earlier postoperative recovery of physical activity, we conducted this study to evaluate postoperative recovery by measuring the physical activity of patients, using an Active tracer AC-301 (ACT) acceleration sensor (GMS, Tokyo, Japan), a device designed for the accelerometric measurement of body movement (Fig. 1). Thus, we measured the cumulative acceleration of body movement and assessed the usefulness of this parameter for evaluating postoperative recovery in terms of the physical activity of patients after different gastric surgery procedures.

Patients

Eighty-two gastric cancer patients surgically treated in our department between June 1998 and December
2002, who gave informed consent to wear an ACT, were included in this study. Patients with preoperative complications that might have resulted in complicated postoperative management and an altered convalescence response, such as cardiovascular, pulmonary, hepatic, or renal dysfunction, were excluded. Seven patients who suffered from postoperative complications within the first 8 postoperative days (POD), such as wound infection (5 patients) or anastomotic dehiscence (2 patients), were also excluded because these complications affected their recovery.

Finally, data from 75 patients, consisting of 48 men and 27 women ranging in age from 42 to 74 years, were analyzed. The patients were divided into three groups according to the surgical intervention performed: namely, laparoscopic partial gastrectomy (LPG, \( n = 20 \)), open distal gastrectomy with gastroduodenal anastomosis (ODG, \( n = 35 \)), and open total gastrectomy reconstructed by pouch-interposition type anastomosis (OTG, \( n = 20 \)). The indications for LPG were tumor invasion confined to the submucosal layer and no evidence of lymph node metastasis. The distribution of patient background characteristics in the three groups is shown in Table 1. There were no significant differences in the male/female ratio or age among the three groups. The staging of gastric cancer, operation times, and intraoperative blood loss were significantly different among the three groups. As two patients in the LPG group were finally confirmed to have stage IB disease, both underwent reoperations as ODG.

### Methods

**Postoperative Care**

During the first 24 h postoperatively, analgesia was given via an epidural cannula. Thereafter, pain was managed with intravenous agents or suppositories as needed, in accordance with patient complaints. On the day after surgery, the nasogastric tube was removed and all patients were encouraged to get out of bed. The intra-abdominal drainage tube was removed on POD 3 in the LPG group, and on POD 6 or 7, 2 days after resuming oral food intake in the ODG group. The patients in the OTG group had two drainage tubes which were kept in place until POD 8–10, just after oral food intake was started, depending on the drainage status.

Oral feeding was recommenced postoperatively in accordance with the protocol of our department; namely, on POD 3 after LPG or on POD 5 after ODG. For the patients who underwent OTG, a radiographic examination of the anastomosed region was done on POD 7 and oral food intake was begun on POD 8, following confirmation that there was no anastomotic dehiscence or any other disorder. These patients were also given total parenteral nutrition (TPN) via a central

### Table 1. Demographics of the patients

<table>
<thead>
<tr>
<th>Group</th>
<th>LPG</th>
<th>ODG</th>
<th>OTG</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>20</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Age (years, mean ± SD)</td>
<td>62.4 ± 12.8</td>
<td>64.2 ± 13.6</td>
<td>61.5 ± 14.3</td>
</tr>
<tr>
<td>Male/female</td>
<td>14/6</td>
<td>21/14</td>
<td>13/7</td>
</tr>
<tr>
<td>Stage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IA</td>
<td>18</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>IB</td>
<td>2</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>0</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>IIIA</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D-number</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Operative times (min)</td>
<td>133.1 ± 54.4*</td>
<td>176.3 ± 49.1**</td>
<td>251.4 ± 60.9</td>
</tr>
<tr>
<td>Intraoperative blood loss (ml)</td>
<td>46.2 ± 28.2*</td>
<td>458.1 ± 226.5**</td>
<td>933.3 ± 457.1</td>
</tr>
</tbody>
</table>

LPG, laparoscopic partial gastrectomy; ODG, open distal gastrectomy; OTG, open total gastrectomy. Stage and D-number were based on the Japanese classification of gastric carcinoma. *P < 0.05 vs ODG and OTG; **P < 0.05 vs LPG and OTG; *P < 0.01 vs ODG and OTG; **P < 0.01 vs LPG and OTG.
venous catheter, which continued for about 2 weeks, and was terminated in each individual according to the amount of oral food they were tolerating. Intravenous fluid infusion was given via a peripheral venous cannula and continued for 5 days postoperatively in the LPG group, and 7 days in the ODG group.

Measurement of Physical Activity

The cumulative acceleration of body movement was measured using an ACT, and the generated data were used as a parameter for estimating postoperative recovery in physical activity. The ACT is a device that continuously measures the gravitational acceleration of body movement by built-in acceleration sensors and hence permits a quantitative evaluation of integrative physical activity. The built-in sensors detect accelerations triaxially in vertical, bilateral, and anteroposterior directions so that body movements are measured in terms of gravity (G). When acceleration exceeds a fixed level (0.05 G in this study) and lasts longer than 0.1s, it is recorded as a single count on a storage device in the ACT. The sensors for the respective directions generate voltages proportional to the accelerations imposed. The generated voltages are then amplified via an amplifier, and the analog signals are converted to digital signals that represent the extent of the acceleration. An ACT device, measuring 56 × 83 × 16 mm and weighing 100 g, was attached to the right ankle of each patient.

We gave a verbal explanation about the measurement to each patient and the ACT device was attached 2 days preoperatively. Except during bathing, the patient wore the device continuously, even in bed, and continuous measurement was carried out until POD 8 when the measurement results were retrieved and analyzed on a computer using Microsoft Excel. Measurement data obtained during the 24h prior to surgery were taken as preoperative values. The data were then collected in consecutive 24-hour periods up until POD 7, starting at 12:00h on the day after surgery. These postoperative values were expressed as a percentage of the preoperative value. The recovery time was defined as the number of days required for restoration to more than 90% of the preoperative value, and the recovery times determined for individual patients were subjected to comparative assessments according to the surgical procedures performed.

Statistical Procedures

Data are expressed as the mean ± standard deviation (SD). The statistical significance of any observed differences was evaluated using the computer software Stat View-J 5.0 (SAS Institute, Cary, NC, USA), and differences among the three groups were assessed for significance using the analysis of variance (ANOVA) test.

Results

Postoperative Outcome (Table 2)

All patients were managed by our protocol in which ambulation is encouraged on POD 1. Every patient in the LPG group began to ambulate the day after their operation, but ambulation began significantly later in the ODG (1.5 ± 0.6 days) and OTG (2.1 ± 1.3 days) groups (P < 0.05). The time until flatus was passed and the day of the first bowel movement; parameters that indicate the recovery of bowel function occurred significantly earlier in the LPG group than in the ODG and OTG groups.

The general condition of all the patients in the LPG group was good enough that discharge would have been possible within 1 week postoperatively. However, due to our management policy, which only allows hospital discharge after confirming the results of a histopathological examination, the postoperative hospital stay in this group averaged 12.8 ± 8.5 days and did not differ significantly from that of the ODG group (16.5 ± 5.8 days). The postoperative hospital stay was significantly longer (31.7 ± 11.4 days) in the OTG group, than in the other two groups.

The postoperative total analgesic dose administered was greatest in the OTG group, followed in order by the

<table>
<thead>
<tr>
<th>Table 2. Postoperative outcome</th>
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<tr>
<td><strong>Group</strong></td>
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<tr>
<td>First mobilization (days)</td>
</tr>
<tr>
<td>Time to pass flatus (days)</td>
</tr>
<tr>
<td>First bowel movement (days)</td>
</tr>
<tr>
<td>Duration of postoperative</td>
</tr>
<tr>
<td>hospital stay (days)</td>
</tr>
<tr>
<td>Analgesic requirement</td>
</tr>
<tr>
<td>(no. of administrations)</td>
</tr>
</tbody>
</table>

* P < 0.05 vs ODG and OTG; ** P < 0.05 vs LPG and OTG; * P < 0.05 vs OTG
ODG group and the LPG group. The differences between the LPG group and the OTG group, and between the LPG group and the ODG group, were significant.

**ACT Measurement Data**

The ACT data obtained are shown in Fig. 2. The upper panel depicts data from a patient who underwent LPG, the middle panel depicts data from a patient who underwent ODG, and the lower panel depicts data from a patient who underwent OTG. In the graphs, the frequency of acceleration events exceeding 0.05 G and lasting for at least 0.1 s is plotted in units per hour on the ordinate, and the lapse of time after the start of measurement is plotted on the abscissa. The LPG patient was capable of physical activities close to the preoperative level the day after the surgery and had recovered to the preoperative level by POD 2. In contrast, in the ODG and OTG patients, the activity was gradually restored, but required 5–7 days to return to the preoperative level, showing obvious differences from the LPG group.

The postoperative progress of mobility restoration, expressed as a percentage of the preoperative 24-h cumulative acceleration value, was also compared among three surgical procedures (Fig. 3). Patients in the LPG group had recovered 48% of the preoperative level of physical activity by POD 1, 85% on POD 2, and as good as the preoperative level on POD 3. In the ODG group, the recovery was about 20% of the preoperative level on POD 1, about 40% on POD 2, and thereafter improved gradually to 90% by POD 6–7. Postoperative recovery in physical activity was significantly delayed in the OTG group compared with the other two groups, being no more than 60% of the preoperative level by 1 week postoperatively.
Intergroup comparisons were also made for the recovery time, defined here as the number of days required for the cumulative recovery to reach more than 90% of the preoperative level (Fig. 4). The recovery time was significantly shorter in the LPG group (2.8 ± 0.9 days) than in the ODG group (6.6 ± 2.1 days). Because a considerable proportion of patients in the OTG group failed to attain the 90% level of recovery even by POD 7, the mean recovery time for this group was calculated by assuming their recovery time to be 8 days (7.8 ± 1.2 days), which was still significantly prolonged compared with the other two groups.

Discussion

With the remarkable technical advances of recent years, operative maneuvers in the abdominal cavity by laparoscopic surgery are now considered to be equal to those of conventional open surgery, including regional lymphadenectomy. In fact, laparoscopic-assisted distal gastrectomy for gastric cancer and laparoscopic-assisted colectomy for colon cancer with lymphadenectomy are frequently performed. Treatments using these procedures are usually accompanied by faster postoperative recovery than operations of the same nature performed via laparotomy, and are therefore perceived to be less invasive; however, the parameters currently employed to evaluate the postoperative recovery status are subjective. Previous studies have shown that laparoscopic surgery results in less pain, allowing for earlier recovery and a shorter hospital stay. Although these clinical benefits are thought to reflect less surgical trauma, various clinical parameters can be affected by the patient's psychosocial background and by the positive attitude of many laparoscopic surgeons. To overcome issues such as possible surgeon bias, a new parameter is needed to evaluate the procedure objectively and quantitatively.

Thus, we sought to assess the postoperative recovery status by means of an acceleration sensor, which enables the continuous measurement of a patient’s voluntary movements, to determine whether the accelerometric measurement might serve as a parameter for the objective and quantitative evaluation of postoperative recovery. ACT has been used in a variety of studies, including an investigation of the relationship between blood pressure and heart rate with physical activity, an analysis of behavioral patterns in mentally retarded individuals, an assessment of the effects of medication on sequelae in cerebral infarction, and an assessment of the physical activity in patients with chronic obstructive lung disease. This study explored the applicability of ACT for assessing postoperative recovery.

Figure 2 shows that a pattern of voluntary movement can be obtained by observing cumulative acceleration measured continuously from before surgery until POD 7. The cumulative acceleration patterns revealed that the postoperative recovery status of physical activity was significantly better after LPG than after ODG and OTG. For a quantitative comparison of the results, the frequency of accelerations exceeding 0.05 G and lasting for at least 0.1 s was calculated for a consecutive 24-h period and compared among groups of patients who underwent different surgical procedures. Because the absolute value of the acceleration of physical activity for an individual varies, the comparative evaluation was conducted with respect to the preoperative 24-h value (%).

The results of this study demonstrated significant differences in postoperative cumulative acceleration, or postoperative physical activity, among surgical procedures considered to be minimally invasive (LPG group), moderately invasive (ODG group), and invasive (OTG group). There were significant differences in all the clinical parameters we used to compare these three groups, such as initial mobilization, time to pass flatus, first bowel movement, time to oral intake, and duration of postoperative hospital stay, indicating clear differences in the degree of surgical stress among the three groups. It seems that the changes in postoperative cumulative acceleration measured using ACT monitoring express the degree of the effect of surgical intervention in quantitative terms.

The data obtained were further analyzed by defining recovery time as the number of days required for recovery...
ery to more than 90% of the preoperative physical activity level, to clarify the postoperative period required for physical activity to be restored to the preoperative level. The LPG group showed recovery to more than 90% of the preoperative physical activity level within 3 POD, whereas it took 6-7 days in the ODG group. None of the OTG group patients had recovered to more than 90% of the preoperative level by POD 7. This implies that the greater the surgical stress, the longer it takes for physical activity to be restored to the preoperative level. These results are considered to represent a quantitative assessment of an otherwise vague impression based on the conventional evaluation of a patient's recovery status in clinical practice.

It is also necessary to consider a variety of factors that could restrict postoperative mobilization, such as the administration of analgesia. 29 All the patients in our series had their pain managed by epidural analgesia during the first 24 h postoperatively, then by intravenous, rectal, or oral agents as required thereafter. Although it is difficult to conclude that postoperative pain ultimately affected mobilization, because susceptibility to pain varies greatly among individuals, 21 the differences observed among the LPG, ODG, and OTG groups may have reflected intergroup differences in pain severity. The potential influence of the drainage tube should also be considered. For example, a Penrose drain was the only drain used in the LPG group, whereas patients in the ODG and OTG groups were required to become ambulatory with a drainage bag for continuous drainage. Another factor may be the route of intravenous fluid administration. All patients were given intravenous fluid infusion postoperatively, and the effect of peripheral versus central venous routes and the duration of infusions on the measurements in this study should be taken into account.

In conclusion, to clinically verify that endoscopic surgery is less invasive than open surgery, we investigated the viability of assessing postoperative recovery status by measuring the acceleration in physical activity as a parameter for evaluating surgical stress. The data obtained indicated that measuring acceleration quantitatively expresses the difference in postoperative physical activity and the time to attain postoperative recovery, which varied with the degree of surgical intervention.

References