Usefulness of measuring temporal changes in physical activity levels using an accelerometer for prediction and early detection of postoperative complications after hepatectomy

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Abstract

Background

This research aimed to determine whether patterns of temporal changes in activity levels can indicate postoperative complications following hepatectomy.

Methods

Between December 2016 and December 2019, 147 patients wore an accelerometer to measure their physical activity levels after hepatectomy until postoperative day 7. Patterns of changes in activity levels were categorized as follows: upward slope type (n=88), wherein activity levels gradually increased; bell curve type (n=13), wherein activity levels initially increased but subsequently decreased; and flat type (n=46), wherein there was no apparent increase in activity levels. Patient characteristics and postoperative complications were compared for each group.

Results

Postoperative complications occurred in 4.5% of patients in the upward slope group, in 76.9% in the bell curve group, and in 65.2% in the flat group ($p<0.001$). Surgical site infections (SSI), refractory pleural effusion, and ascites were more common in the bell curve group, while pneumonia was only observed in the flat group.

Discussion

SSI, pleural effusion, and ascites should be considered when previously increasing activity levels decline during the postoperative period. In addition, there is a high risk of SSI and pneumonia when activity levels do not increase at all after surgery.

Introduction

In recent years, populations of developed countries have been aging, and increasing numbers of older patients have been undergoing surgeries such as hepatectomy. Several reports have compared postoperative complication rates after hepatectomy between older patients and younger patients. The rates of postoperative complications after hepatic resection have been shown to be similar in the two age groups[1-3]. However, there have been reports that older patients tend to develop more serious complications than younger patients[4-7]. When postoperative complications occur, older patients have a higher risk of severe consequences due to their increased fragility. It has been concluded that hepatectomy can be performed safely in carefully selected older patients[3, 8]. However, postoperative complications result in increases in the duration of hospitalization, use of medications, and medical expenses. In addition, postoperative complications can lead to loss of independence in older patients after discharge[9]. Therefore, it is crucial to prevent and predict postoperative complications in older patients after hepatectomy.

Classification systems for preoperative predictors of postoperative complications include the American Society of Anesthesiologists (ASA) physical status classification system and the Eastern Cooperative Oncology Group performance status scale[10-14]. However, these consider only subjective factors, making their accuracy and objectivity uncertain. In contrast, objective measures such as frequent blood tests and radiological imaging are useful for the early detection of post-hepatectomy complications. However, repeatedly performing these tests can place a huge burden on patients. Therefore, it is desirable to develop an objective predictor of postoperative complications that lessens the burden on patients.

To this end, this study investigated the use of accelerometers for the prediction of postoperative complications. Accelerometers contain acceleration sensors that can measure activity parameters, including distance walked, duration of sitting and lying, and stair ascent and descent. Calorie consumption can be calculated precisely by measuring exercise intensities[15]. Thus, a pilot study was conducted in which patients wore accelerometers after hepatectomy. The association between patterns of changing physical activity levels and postoperative complications was investigated[16]. The findings of the pilot study indicated that patterns of temporal changes in activity levels following hepatectomy could be divided into 3 distinct types: upward slope type, bell curve type, and flat type; it was concluded that accelerometers might be useful in predicting postoperative complications. Therefore, the aim of this research was to verify the findings of the pilot study.

Patients and methods

Patients

This prospective observational study involved patients who underwent hepatectomy between December 2016 and December 2019 at Shiga University of Medical Science Hospital. Patients who underwent combined resection of other organs, continued intubation for respiratory management after surgery, or had difficulty wearing an accelerometer due to dementia were excluded. The 147 enrolled patients had their physical activity levels continuously measured, 24 hours a day, from postoperative day (POD) 1 to POD 7, and these data were then analyzed.

Accelerometry

The MTN/220 accelerometer (ACOS Co., Ltd., Nagano, Japan) was used to monitor physical activity. The accelerometer consisted of a three-dimensional acceleration sensor and a computer that calculated basal metabolic rate, momentum, moment of momentum, number of steps, and exercise intensity based on the age, height, and weight of the wearer. Momentum was calculated using a 64-level acceleration index of exercise intensity, based on the amplitude and vibration frequency data from the acceleration sensor, multiplied by body weight. All measurements were made continuously, and the most reliable value was recorded in the device every 2 minutes. Data were extracted from the accelerometer through a near-field communication interface (PaSoRi RC-S380; Sony Co., Ltd., Tokyo, Japan) using SleepSign Act software (Kissei Comtec Co., Ltd., Nagano, Japan)[17, 18].

Evaluation

All patients wore the accelerometer on their waist continuously from POD 1 to POD 7. Data automatically recorded in the device were analyzed. The amount of daily physical activity was calculated as total energy expenditure per day, excluding basal metabolic rate. Postoperative rehabilitation for all patients was started from POD 1. Before starting this study, we consulted with the physical therapists to ensure that the intensity of rehabilitation between patients would not be biased. Bedside rehabilitation was performed on POD 1, and walking training was conducted in the hospital ward on POD 2. From POD 3, if the blood pressure, heart rate, and body temperature were normal, the patients moved to the rehabilitation room and performed walking training. Based on 6 minutes of walking training, the dose was increased or decreased according to the patient's condition. Patients were categorized into three groups according to patterns of changes in their activity levels: (1) upward slope type (n = 88), wherein activity level gradually increased; (2) bell curve type (n = 13), wherein activity level initially increased but subsequently decreased; and (3) flat type (n = 46), wherein there was no apparent increase in activity level[16].

Patient characteristics, including age, gender, body mass index (BMI), diabetes mellitus (DM), history of alcohol abuse, etiology, cardiovascular disease, and primary disease, were compared among the three groups. Blood test results, including albumin level, alanine aminotransferase (ALT) level, aspartate aminotransferase (AST) level, total bilirubin level, prothrombin activity, platelet count, indocyanine green retention rate at 15 minutes (ICGR15), white blood count (WBC), and C-reactive protein (CRP) levels, were also compared. Surgical factors, including the surgical method (laparoscopic or open), extent of resection (anatomical or partial), repeat hepatectomy, blood loss, and operative time, were also compared. Finally, postoperative complications, including surgical site infection (SSI), post-hepatectomy liver failure (PHLF), and bile leakage, were compared. Other postoperative complications were defined based on the Clavien-Dindo classification and were included if they were classified as Grade II or higher[19]. In the case of PHLF, complications were included if they were classified as International Study Group of Liver Surgery Grade B or higher[20] since Grade A PHLF does not affect the postoperative course. For diagnosis of SSI, the Center for Disease Control and Prevention guidelines were used[21, 22]. Refractory pleural effusion or ascites was included as a postoperative complication only if puncture drainage was necessary.

Statistical analysis

Patient age and BMI are presented as means ± standard deviations. Other continuous variables are expressed as medians and interquartile ranges. For comparisons between the 3 groups, continuous variables were analyzed using a one-way ANOVA or Kruskal-Wallis test, while nominal variables were analyzed using a chi-square test or Fisher's exact test. The significance level was set at $p < 0.05$. All statistical analyses were performed using R statistical software, version 4.0.2. (The R Foundation for Statistical Computing, Vienna, Austria; https://cran.r-project.org/bin/macosx/).

Results

Mean patient ages were similar in the three groups. There were also no significant differences in gender, DM, history of alcohol abuse, cardiovascular disease, or primary disease. However, patients in the bell curve group had significantly lower BMI ($p = 0.03$), and a significant proportion had hepatitis C viral infections ($p = 0.03$). Regarding preoperative blood tests, there were no significant differences in albumin level, AST level, ALT level, total bilirubin level, prothrombin activity, platelet count, ICGR15, WBC, or CRP level. Regarding surgical factors, 67.0% of patients in the upward slope group had undergone laparoscopic hepatectomy, compared with 30.8% of patients in the bell curve group and 50.0% of patients in the flat group ($p = 0.02$). Further, the upward slope group included significantly more cases of partial hepatectomy ($p = 0.001$). Patients in the upward slope group also had significantly shorter operative times and less blood loss ($p < 0.001$ for both). However, the proportion of patients who underwent repeat hepatectomy was similar among the 3 groups (Table 1).

Figure 1 presents changes in physical activity levels for each group from POD 1 to POD 7. In the upward slope group, a continuous increase in activity levels was observed until POD 7. In the bell curve group, activity levels displayed an initial increase, followed by a gentle decline from POD 5. In contrast, in the flat group, no increase in activity levels could be observed by POD 7 (Figure 1).

Postoperative complications (Clavien-Dindo classification Grade II or higher) developed in 4.5% of patients in the upward slope group, 76.9% in the bell curve group, and 65.2% in the flat group ($p < 0.001$). Rates of SSI were 30.8% in the bell curve group and 23.9% in the flat group, while no SSI occurred in the upward slope group. In addition, 1.1% of patients in the upward slope group, 15.4% in the bell curve group, and 19.6% in the flat group had Grade B or C PHLF ($p = 0.005$). There were no cases of bile leakage in the upward slope group, but 7.7% of patients in the bell curve type and 13.0% in the flat type developed this complication ($p = 0.003$). Furthermore, no patients in the upward slope group developed infectious complications, and patients in this group had a significantly shorter hospitalization period (Table 2).

Table 3 displays details of the patients' postoperative complications. Of the 88 patients who displayed upward slope patterns of activity levels, 4 developed postoperative complications: 2 cases of postoperative thrombosis, 1 case of postoperative ileus, and 1 case of Grade B PHLF. No infectious complications were observed in this group. Of the 13 patients who displayed bell curve patterns of activity levels, 10 developed postoperative complications, including 5 cases of refractory pleural effusion or ascites that required puncture drainage, which was the most common complication in this group. Another 3 patients developed organ or space SSI. There was also 1 case of postoperative bile duct strictures; re-operation was performed, but the patient died of Grade C PHLF. Of the 46 patients who displayed flat patterns of activity levels, 30 developed postoperative complications, including 10 cases of organ or space SSI. There were also 4 patients who developed pneumonia, with this complication only being observed in patients in the flat group. Various complications, including thrombosis, bleeding, ileus, refractory pleural effusion or ascites, and delirium, were observed in patients in the flat group (Table 3).

Figure 2 displays individual patterns of activity levels and dates of detection of postoperative complications for the 10 patients in the bell curve group who developed postoperative complications. In all cases, complications were detected after declines in physical activity levels were observed.

Discussion

In recent years, accelerometers have become popular due to the growing health-conscious population. However, few reports involving these wearable devices have been published in the field of gastrointestinal surgery. In fact, the authors of the current paper were the first to report an association between physical activity levels and postoperative complications in the field of gastrointestinal surgery[16]. Following this, another study was published in 2020, which examined the relationship between gastrointestinal surgery and postoperative complications in 19 patients[23]. The aim of the present study was to verify the results of our previous pilot study. A total of 147 patients were included in this research; this is the first study of accelerometers in the field of gastrointestinal surgery to have such a large sample size.

Due to alterations in eating habits, developed countries are now confronted with increased numbers of patients with metabolic syndrome, obesity, DM, and hyperlipidemia[24, 25]. These countries have been seeking methods to prevent the occurrence of these diseases since they carry a high risk of cardiovascular disease[26, 27]. Many researchers have reported that daily physical activity level is strongly associated with obesity, DM, and hyperlipidemia[28-30]. Since the 2000s, accelerometers have therefore become popular in preventive medicine, and they have subsequently gained popularity in surgical fields. In fields such as cardiovascular surgery, orthopedics, and bariatric surgery, postoperative rehabilitation is compulsory. Thus, many studies of postoperative physical activity levels have been conducted in cardiovascular surgery[31, 32], orthopedics surgery[33-37], and bariatric surgery[38].

The current study found that only 4.5% of patients in the upward slope group developed postoperative complications, and there were no cases of infectious complications in this group. Complication rates in the bell curve group and the flat group were 76.9% and 65.2%, respectively. Of particular interest is that characteristics of postoperative complications in the bell curve group were distinct from those in the flat group. Common complications in the bell curve group were refractory pleural effusion or ascites and organ or space SSI, while organ or space SSI and pneumonia were common in the flat group. The proportion of postoperative complications that were organ or space SSI were similar in the bell curve group (3 cases of organ or space SSI out of 10 complications; 30%) and the flat group (10 out of 30 complications; 33%). This indicates that, when organ or space SSI occurs, patients may display either a bell curve pattern or a flat pattern of activity levels. In contrast, pneumonia was only observed in patients who displayed a flat pattern. This suggests that prolonged recumbency after surgery may be a risk factor for pneumonia. This is consistent with a previous report that postoperative rehabilitation can lessen the occurrence of pulmonary complications[39]. Further, refractory pleural effusion/ascites frequently occurred in patients who displayed a bell curve pattern; the late-onset decrease in activity levels seen in this group may have been caused by the gradual accumulation of pleural fluid and development of ascites.

The primary aim of this study was to determine whether monitoring patterns of temporal changes in physical activity levels is useful for the prediction and early detection of postoperative complications. This study demonstrated that when the physical activity level increases steadily over time (upward slope pattern), the patient is highly unlikely to develop postoperative complications. In contrast, a patient whose activity level does not increase after surgery (flat pattern) may be at a higher risk of developing postoperative complications. While various kinds of complications may occur in patients with flat patterns of activity, organ or space SSI and pneumonia, especially, should be carefully considered. In a patient whose activity level decreases after a temporary increase (bell curve pattern), refractory pleural effusion or ascites and organ or space SSI are possibilities. These findings suggest that postoperative activity levels decrease due to the occurrence of postoperative complications. This study examined all 10 cases of postoperative complications in patients with bell curve patterns and compared the time when activity levels began to decrease with the time when postoperative complications were detected. In all cases, activity levels began to fall before complications were confirmed. This result suggests that the primary physician was unaware of the onset of postoperative complications, leading to the delay in diagnosis. Therefore, the occurrence of postoperative complications should be suspected when a patient's physical activity level decreases following an initial postoperative increase. Complications can be detected during their early stages by conducting blood tests and imaging tests as soon as possible after suspicious changes in activity levels are observed. In the future, it is expected that postoperative complications can be diagnosed, and timely treatment can be started by monitoring the activity levels of individual patients in real time.

Although this study has the largest sample size of any study of accelerometers in gastrointestinal surgery to date, its single-center design is a limitation. Additionally, this study did not measure physical activity levels prior to surgery. Some reports have demonstrated that preoperative rehabilitation is useful for increasing physical activity levels. Therefore, measuring preoperative and postoperative activity levels is recommended for future studies[40-42]. Currently, we provided accelerometers to preoperative outpatients to measure their daily activity levels. In the future, we plan to investigate whether preoperative activity levels correlate with postoperative activity levels and postoperative complication rates. Another limitation is that physical activity levels were only recorded during the first week after surgery. Although the average duration of hospitalization was approximately 10 days, activity levels were only measured until POD 7. Thus, associations between activity levels and postoperative complications that developed after the first week were not analyzed. There is a need for further studies that include a larger number of patients of a heterogeneous population from multiple facilities in Japan and possibly from many countries and measure activity levels from the preoperative stage until discharge.

In conclusion, monitoring patterns of temporal changes in physical activity levels may be useful for the prediction and early detection of postoperative complications after hepatectomy.

Acknowledgments

Not applicable.

Ethical declaration

This prospective observational study conformed to the Clinical Research Guidelines and was approved by the ethical committee of our institution (Institutional approval number: R2017-191). Written informed consent was obtained from all patients. In addition, this study was registered in a national registry (UMIN000030389).

Conflicts of interest

The authors have no related conflicts of interest to declare.

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Author contributions

HI, TS, and MT designed the research and analyzed the patient data. HI, HM, HM, KT, MK, TU, SK, TM, and KT performed the data collection. HI drafted the manuscript. All authors read and approved the final version of the manuscript.

References

1. Kaibori M, Matsui K, Ishizaki M, Saito T, Kitade H, Matsui Y *et al.* (2009) Hepatic resection for hepatocellular carcinoma in the elderly. *J Surg Oncol* 99:154-160.

2. Iida H, Kaibori M, Matsui K, Ishizaki M, Kon M. (2017) Assessing the feasibility of clinicopathological features of hepatic resection for hepatocellular carcinoma in patients over 80 years of age. *Mol Clin Oncol* 6:29-38.

3. Wu FH, Shen CH, Luo SC, Hwang JI, Chao WS, Yeh HZ *et al.* (2019) Liver resection for hepatocellular carcinoma in oldest old patients. *World J Surg Oncol* 17.

4. Reddy SK, Barbas AS, Turley RS, Gamblin TC, Geller DA, Marsh JW *et al.* (2011) Major liver resection in elderly patients: a multi-institutional analysis. *J Am Coll Surg* 212:787-795.

5. Nanashima A, Abo T, Nonaka T, Fukuoka H, Hidaka S, Takeshita H *et al.* (2011) Prognosis of patients with hepatocellular carcinoma after hepatic resection: are elderly patients suitable for surgery? *J Surg Oncol* 104:284-291.

6. Nozawa A, Kubo S, Takemura S, Sakata C, Urata Y, Nishioka T *et al.* (2015) Hepatic resection for hepatocellular carcinoma in super-elderly patients aged 80 years and older in the first decade of the 21st century. *Surg Today* 45:851-857.

7. Van Tuil T, Dhaif AA, Te Riele WW, Van Ramshorst B, Van Santvoort HC. (2019) Systematic Review and Meta-Analysis of Liver Resection for Colorectal Metastases in Elderly Patients. *Digestive Surgery* 36:111-123.

8. Shirabe K, Kajiyama K, Harimoto N, Gion T, Tsujita E, Abe T *et al.* (2009) Early outcome following hepatic resection in patients older than 80 years of age. *World J Surg* 33:1927-1932.

9. Tanaka S, Iida H, Ueno M, Hirokawa F, Nomi T, Nakai T *et al.* (2019) Preoperative Risk Assessment for Loss of Independence Following Hepatic Resection in Elderly Patients: A Prospective Multicenter Study. *Ann Surg*. https://doi.org/10.1097/sla.0000000000003585.

10. Owens WD, Felts JA, Spitznagel EL, Jr. (1978) ASA physical status classifications: a study of consistency of ratings. *Anesthesiology* 49:239-243.

11. Haynes SR, Lawler PG. (1995) An assessment of the consistency of ASA physical status classification allocation. *Anaesthesia* 50:195-199.

12. Ranta S, Hynynen M, Tammisto T. (1997) A survey of the ASA physical status classification: significant variation in allocation among Finnish anaesthesiologists. *Acta Anaesthesiol Scand* 41:629-632.

13. Mak PH, Campbell RC, Irwin MG. (2002) The ASA Physical Status Classification: inter-observer consistency. American Society of Anesthesiologists. *Anaesth Intensive Care* 30:633-640.

14. Oken MM, Creech RH, Tormey DC, Horton J, Davis TE, McFadden ET *et al.* (1982) Toxicity and response criteria of the Eastern Cooperative Oncology Group. *Am J Clin Oncol* 5:649-655.

15. Bouten CVC, Koekkoek KTM, Verduin M, Kodde R, Janssen JD. (1997) A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity. *IEEE Transactions on Biomedical Engineering* 44:136-147.

16. Iida H, Shimizu T, Maehira H, Kitamura N, Mori H, Miyake T *et al.* (2018) A pilot study: The association between physical activity level using by accelerometer and postoperative complications after hepatic resection. *Exp Ther Med* 16:4893-4899.

17. Nakazaki K, Kitamura S, Motomura Y, Hida A, Kamei Y, Miura N *et al.* (2014) Validity of an algorithm for determining sleep/wake states using a new actigraph. *J Physiol Anthropol* 33:31.

18. Matsuo M, Masuda F, Sumi Y, Takahashi M, Yamada N, Ohira MH *et al.* (2016) Comparisons of Portable Sleep Monitors of Different Modalities: Potential as Naturalistic Sleep Recorders. *Front Neurol* 7:110.

19. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD *et al.* (2009) The Clavien-Dindo classification of surgical complications: five-year experience. *Ann Surg* 250:187-196.

20. Rahbari NN, Garden OJ, Padbury R, Brooke-Smith M, Crawford M, Adam R *et al.* (2011) Posthepatectomy liver failure: a definition and grading by the International Study Group of Liver Surgery (ISGLS). *Surgery* 149:713-724.

21. Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR. (1999) Guideline for Prevention of Surgical Site Infection, 1999. Centers for Disease Control and Prevention (CDC) Hospital Infection Control

Practices Advisory Committee. *Am J Infect Control* 27:97-132; quiz 133-134; discussion 196.

22. Berríos-Torres SI, Umscheid CA, Bratzler DW, Leas B, Stone EC, Kelz RR *et al.* (2017) Centers for Disease Control and Prevention Guideline for the Prevention of Surgical Site Infection, 2017. *JAMA Surg* 152:784-791.

23. Barkley R, Khalil M, Shen P, Levine EA, Votanopoulos K, Clark CJ. (2020) Feasibility of low-cost accelerometers in measuring functional recovery after major oncologic surgery. *J Surg Oncol* 121:279-285.

24. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. (2008) Physical activity in the United States measured by accelerometer. *Med Sci Sports Exercise* 40:181-188.

25. Bankoski A, Harris TB, McClain JJ, Brychta RJ, Caserotti P, Chen KY *et al.* (2011) Sedentary activity associated with metabolic syndrome independent of physical activity. *Diabetes Care* 34:497-503.

26. Healy GN, Matthews CE, Dunstan DW, Winkler EAH, Owen N. (2011) Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 200306. *Euro Heart J* 32:590-597.

27. Stamatakis E, Hamer M, Tilling K, Lawlor DA. (2012) Sedentary time in relation to cardio-metabolic risk factors: differential associations for self-report vs accelerometry in working age adults. *Int J Epidemiol* 41:1328-1337.

28. Trost SG, Kerr LM, Ward DS, Pate RR. (2001) Physical activity and determinants of physical activity in obese and non-obese children. *Int J Obesity* 25:822-829.

29. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ *et al.* (2007) Objectively measured light-intensity physical activity is independently associated with 2-h plasma glucose. *Diabetes Care* 30:1384-1389.

30. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ *et al.* (2008) Objectively measured sedentary time, physical activity, and metabolic risk the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Diabetes Care* 31:369-371.

31. Cook DJ, Thompson JE, Prinsen SK, Dearani JA, Deschamps C. (2013) Functional recovery in the elderly after major surgery: assessment of mobility recovery using wireless technology. *Ann Thorac Surg* 96:1057-1061.

32. Takahashi T, Kumamaru M, Jenkins S, Saitoh M, Morisawa T, Matsuda H. (2015) In-patient step count predicts re-hospitalization after cardiac surgery. *J Cardiology* 66:286-291.

33. Taraldsen K, Sletvold O, Thingstad P, Saltvedt I, Granat MH, Lydersen S *et al.* (2014) Physical behavior and function early after Hip Fracture surgery in patients receiving comprehensive geriatric care or orthopedic care - A randomized controlled trial. *J Gerontology - Series A Biol Sci Med Sci* 69 A:338-345.

34. Harding P, Holland AE, Delany C, Hinman RS. (2014) Do activity levels increase after total hip and knee arthroplasty? *Clin Orthopaedics Relate Res* 472:1502-1511.

35. Harding PA, Holland AE, Hinman RS, Delany C. (2015) Physical activity perceptions and beliefs following total hip and knee arthroplasty: a qualitative study. *Physiother Theory Pract* 31:107-113.

36. Toogood PA, Abdel MP, Spear JA, Cook SM, Cook DJ, Taunton MJ. (2016) The monitoring of activity at home after total hip arthroplasty. *Bone Joint J* 98-B:1450-1454.

37. Schotanus MGM, Bemelmans YFL, Grimm B, Heyligers IC, Kort NP. (2017) Physical activity after outpatient surgery and enhanced recovery for total knee arthroplasty. *Knee Surgery, Sports Traumatology, Arthroscopy* 25:3366-3371.

38. Bond DS, Jakicic JM, Vithiananthan S, Thomas JG, Leahey TM, Sax HC *et al.* (2010) Objective quantification of physical activity in bariatric surgery candidates and normal-weight controls. *Surg Obesity Relate Dis* 6:72-78.

39. Chumillas S, Ponce JL, Delgado F, Viciano V, Mateu M. (1998) Prevention of postoperative pulmonary complications through respiratory rehabilitation: a controlled clinical study. *Arch Phys Med Rehabil* 79:5-9.

40. Li C, Carli F, Lee L, Charlebois P, Stein B, Liberman AS *et al.* (2013) Impact of a trimodal prehabilitation program on functional recovery after colorectal cancer surgery: a pilot study. *Surg Endosc* 27:1072-1082.

41. Gillis C, Li C, Lee L, Awasthi R, Augustin B, Gamsa A *et al.* (2014) Prehabilitation versus rehabilitation: a randomized control trial in patients undergoing colorectal resection for cancer. *Anesthesiology* 121:937-947.

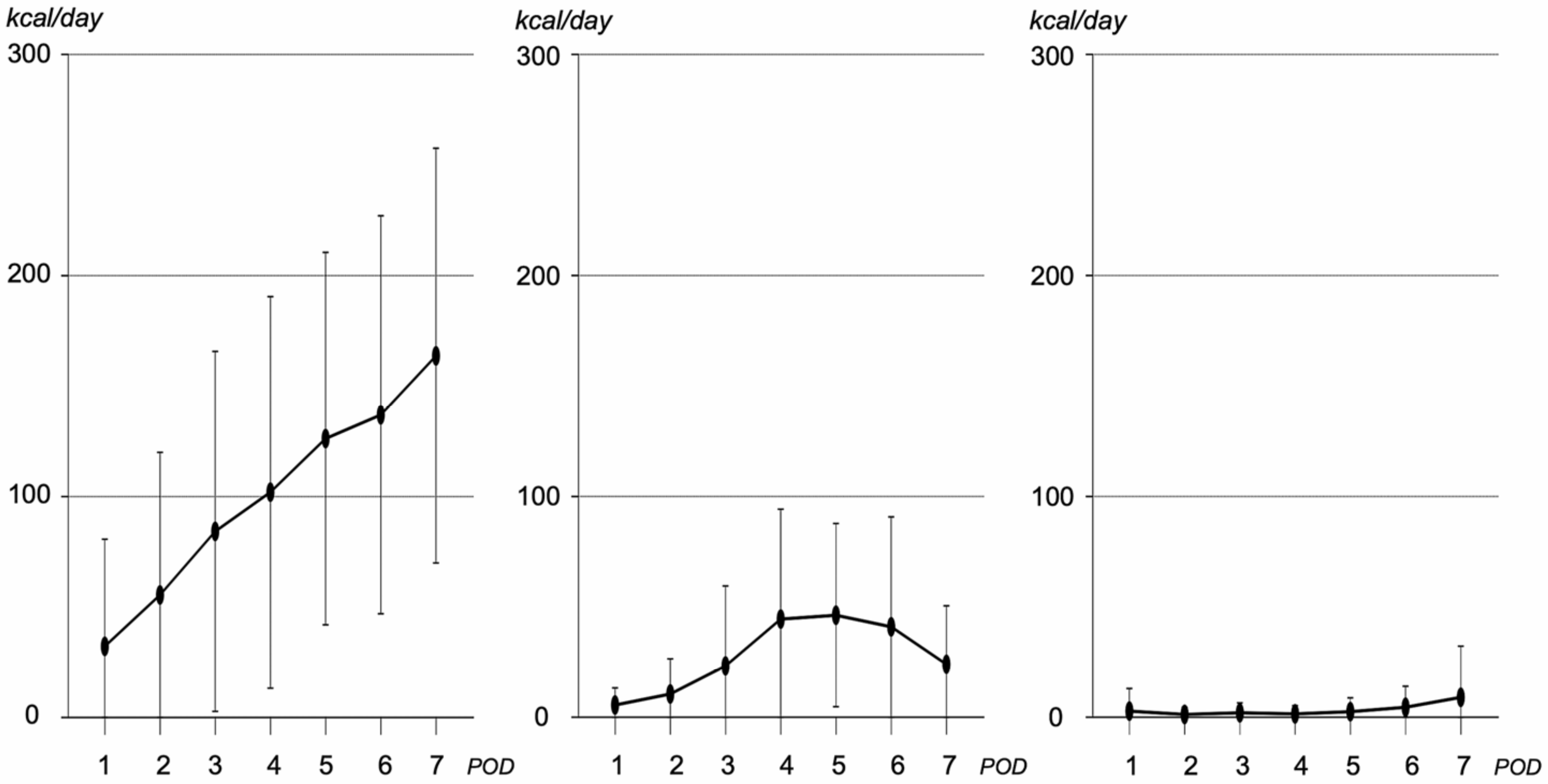
42. Grimes L, Outtrim JG, Griffin SJ, Ercole A. (2019) Accelerometery as a measure of modifiable physical activity in high-risk elderly preoperative patients: a prospective observational pilot study. *BMJ Open* 9.

Figure legends

Figure 1: Patterns of changes in physical activity levels from postoperative day (POD) 1 to POD 7: (a.) upward slope type, (b.) bell curve type, (c.) flat type

Figure 2: Changes in physical activity and timings of complication detection in 10 patients with bell curve patterns of physical activity who developed postoperative complications

A decrease in activity level is evident in all cases prior to the detection of complications.



Mean	32	56	84	102	126	137	164	
SD	48	64	81	89	84	90	94	Kcal/day

a.

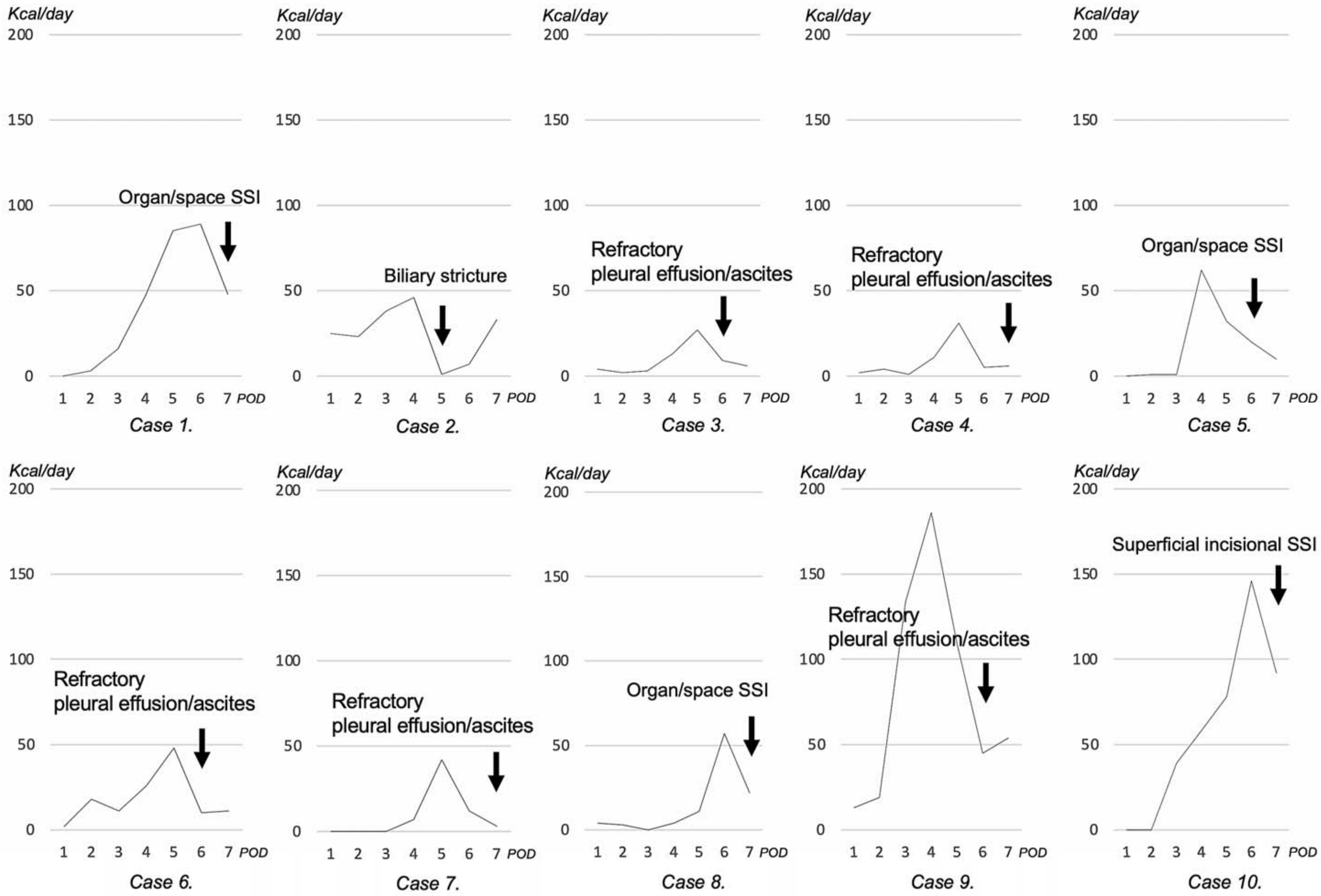
Mean	5.6	10.6	23.4	44.5	46.3	41.1	24.0	
SD	7.6	16.0	36.0	49.7	41.4	49.7	26.5	Kcal/day

b.

Mean	2.8	1.3	2.1	1.7	2.5	4.5	9.0	
SD	10.1	3.1	4.5	3.5	6.2	9.6	23.2	Kcal/day

c.

Figure 1



Kcal/day
200
150
100
50
0
1 2 3 4 5 6 7 POD
Organ/space SSI
Case 1.
Biliary stricture
Case 2.
Refractory
pleural effusion/ascites
Case 3.
Refractory
pleural effusion/ascites
Case 4.
Organ/space SSI
Case 5.
Refractory
pleural effusion/ascites
Case 6.
Refractory
pleural effusion/ascites
Case 7.
Organ/space SSI
Case 8.
Refractory
pleural effusion/ascites
Case 9.
Superficial incisional SSI
Case 10.

Figure 2

Table 1: Comparison of background factors, laboratory findings, and surgical factors between patients displaying different patterns of changes in postoperative physical activity levels

		Upward slope (n = 88)	Bell curve (n = 13)	Flat (n = 46)	p-value
Age (years)		68.0 ± 11.5	71.9 ± 9.1	70.2 ± 10.4	0.345
Gender (n, %)	Female	31 (35.2)	2 (15.4)	12 (26.1)	0.253
	Male	57 (64.8)	11 (84.6)	34 (73.9)	
Body mass index (kg/m^2)		23.3 ± 3.5	20.8 ± 3.0	23.8 ± 3.9	0.034
Diabetes mellitus (n, %)		26 (29.5)	5 (38.5)	15 (32.6)	0.789
Alcohol abuse (n, %)		27 (30.7)	7 (53.8)	18 (39.1)	0.215
Etiology (n, %)	HBV	5 (5.7)	0 (0.0)	1 (2.2)	0.03
	HCV	11 (12.5)	6 (46.2)	12 (26.1)	
	NBNC	72 (81.8)	7 (53.8)	33 (71.7)	
Cardiovascular disease (n, %)		5 (5.7)	1 (7.7)	8 (17.4)	0.088
Primary disease (n, %)	HCC	46 (52.3)	8 (61.5)	30 (65.2)	0.298
	Meta	28 (31.8)	2 (15.4)	13 (28.3)	
	Other	14 (15.9)	3 (23.1)	3 (6.5)	
Albumin (g/dL)		4.0 [3.6, 4.2]	3.9 [3.8, 4.2]	3.9 [3.5, 4.1]	0.395
ALT (IU/L)		23 [15, 31]	21 [16, 26]	31 [16, 47]	0.299
AST (IU/L)		26 [20, 42]	36 [23, 54]	32 [21, 50]	0.182
Total bilirubin (mg/dL)		0.68 [0.51, 0.89]	0.69 [0.58, 0.84]	0.57 [0.47, 0.83]	0.438
Prothrombin activity (%)		101 [91, 111]	93 [86, 109]	94 [86, 106]	0.193
Platelet count (x10^4/μL)		161 [118, 214]	156 [127, 180]	155 [121, 222]	0.833
ICGR15 (%)		9.9 [5.2, 17.5]	12.8 [7.1, 15.3]	12.1 [8.4, 20.0]	0.292
White blood count (x10^4/μL)		4.7 [3.8, 5.5]	4.2 [4.2, 4.7]	4.8 [4.2, 6.6]	0.207
C-reactive protein (mg/dL)		0.12 [0.06, 0.21]	0.10 [0.04, 0.28]	0.12 [0.06, 0.41]	0.609
Laparoscopic hepatectomy (n, %)		59 (67.0)	4 (30.8)	23 (50.0)	0.017
Operative methods (n, %)	Partial	63 (71.6)	4 (30.8)	21 (45.7)	0.001
	Anatomical	25 (28.4)	9 (69.2)	25 (54.3)	
Repeat hepatectomy (n, %)		26 (29.5)	4 (30.8)	13 (28.3)	0.98
Blood loss (mL)		99 [0, 300]	602 [322, 1022]	457 [121, 790]	< 0.001
Operative time (min)		210 [159, 271]	290 [259, 328]	279 [212, 347]	< 0.001

Abbreviations: HBV, hepatitis B virus; HCV, hepatitis C virus; NBNC, negative for hepatitis B and hepatitis C virus; HCC, hepatocellular carcinoma; Meta, metastasis; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ICGR15, indocyanine green retention rate at 15 minutes.

Age and body mass index are expressed as mean ± standard deviation. Other data are expressed as median with 25th and 75th percentiles.

Table 2: Comparison of postoperative complications between patients displaying different patterns of changes in postoperative physical activity levels

		Upward slope (n = 88)	Bell curve (n = 13)	Flat (n = 46)	p-value
All complications (n, %)		4 (4.5)	10 (76.9)	30 (65.2)	< 0.001
Surgical site infection (n, %)		0 (0.0)	4 (30.8)	11 (23.9)	< 0.001
PHLF (n, %)	Grade B	1 (1.1)	1 (7.7)	5 (10.9)	0.005
	Grade C	0 (0.0)	1 (7.7)	4 (8.7)	
Bile leakage (n, %)		0 (0.0)	1 (7.7)	6 (13.0)	0.003
Infectious complications (n, %)		0 (0.0)	4 (30.8)	16 (34.8)	< 0.001
Duration of hospitalization (days)		9 [8, 12]	14 [11, 33]	12 [10, 22]	< 0.001

Abbreviations: PHLF, post-hepatectomy liver failure.
Duration of hospitalization (days) is expressed as median with 25^{th} and 75^{th} percentiles.

Table 3: Details of postoperative complication frequencies in groups of patients displaying different patterns of changes in postoperative physical activity levels

Upward slope (n = 4/88, 4.5%)		Bell curve (n = 10/13, 76.9%)		Flat (n = 30/46, 65.2%)	
Thrombosis (portal)	(n = 2)	Refractory pleural effusion or ascites (including 1 case of Grade B PHLF)	(n = 5)	Organ or space SSI (including 6 cases of bile leakage, 3 cases of Grade B PHLF, and 2 cases of Grade C PHLF)	(n = 10)
Ileus	(n = 1)	Organ or space SSI (including 1 case of bile leakage)	(n = 3)	Pneumonia	(n = 4)
Grade B PHLF	(n = 1)	Superficial incisional SSI	(n = 1)	Thrombosis (3 cases of portal thrombosis and 1 case of pulmonary thrombosis)	(n = 4)
		Biliary stricture with Grade C PHLF	(n = 1)	Postoperative bleeding (including 2 cases of Grade B PHLF)	(n = 3)
				Ileus	(n = 2)
				Refractory pleural effusion or ascites	(n = 2)
				Delirium	(n = 2)
				Superficial incisional SSI	(n = 1)
				Infection of implant with Grade C PHLF	(n = 1)
				Grade C PHLF	(n = 1)

Abbreviations: PHLF, post-hepatectomy liver failure; SSI, surgical site infection