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ORIGINAL ARTICLE

Perioperative continuous body weight measurements with load cells under the bed legs in patients undergoing abdominal surgery

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BACKGROUND Both excessive positive fluid balance and body weight increase after surgery are risk factors for poor postoperative outcomes. The use in clinical practice and the value of perioperative body weight measurements are unclear at present, possibly due to difficulty in measuring body weight in patients lying on the bed and insufficient clinical research.

OBJECTIVES To investigate the relationship between intraoperative fluid balance and body weight change and perioperative nightly body weight change pattern throughout the hospital stay with contact-free unconstraint load cells placed under the bed legs.

DESIGN Observational and exploratory study.

SETTING A single university hospital.

PATIENTS Twenty adult patients were undergoing elective abdominal surgery under general anaesthesia.

MAIN OUTCOME MEASURES Body weight.

RESULTS Immediately after surgery, body weight increased significantly by 2.7 ± 1.3 kg, equivalent to a 5% increase from the preoperative body weight. This increase was not correlated with ($P = 0.178$) the intraoperative fluid balance and was significantly greater than the intraoperative fluid balance 1.5 ± 0.4 kg ($P < 0.001$). The body weight returned to the preoperative level on postoperative day (POD)3 and further significantly decreased to 97% of the preoperative body weight at POD6 ($P < 0.001$). This physiological nocturnal weight loss pattern was maintained throughout hospitalisation except when fluid was infused. Compared with their preoperative status, patients stayed in bed longer with smaller body movements and left the bed less frequently during the daytime until POD3. Conversely, the patients had greater body movements in bed during the night leading to smaller diurnal variation in the body movements in bed after POD4.

CONCLUSION Both perioperative fluid balance calculation and body weight measurement may have different but mutually complementary roles in perioperative managements. Postoperative fluid and nutrition management strategies are potentially new directions for treatment through continuous weight monitoring during the perioperative period.

Trial registration : UMIN Clinical Trials Registry (UMIN000040164).

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KEY POINTS

- This vital sign monitor, free of patient contact, is a new method for monitoring weight changes and the postoperative recovery process over the course of the perioperative week.
- Intraoperative weight changes measured by this new method did not correlate with changes in fluid balance calculation.
- Both perioperative fluid balance calculation and body weight measurement may have different and mutually complementary roles in perioperative managements.

Introduction

Excessive fluid infusion during surgery causes surgical site oedema as well as an increase in total body weight, potentially leading to postoperative poor outcomes such as surgical site infection, anastomotic leakage, postoperative respiratory and kidney dysfunction.[1–3] Daily or hourly fluid balance calculations are a routine clinical practice during and after surgery, and a positive fluid balance is evidenced to be an independent risk factor for postoperative morbidity and mortality in patients undergoing abdominal and cardiac surgery.[2,4,5] Body weight gain, another variable in the pathophysiological pathway mentioned above, is also reported to be an independent predictor of postoperative outcomes.[3,4] Changes of fluid balance and body weight, however, do not always accord with each other, and their correlation was modest, and that was only during early postoperative days (PODs), suggesting they may play different roles in postoperative patient management.[6–9] However, no study has evaluated body weight change immediately after surgery and its correlation with intraoperative fluid balance in patients undergoing abdominal surgery, possibly due to difficulty in measuring body weight in patients lying in bed. In most previous studies, body weight was measured only once a day in the morning from POD 1 to 7 and only after the patients were able to stand on normal weighing scales.[1,6,7]

Recently, we developed body a vital signs and weight monitor using high-resolution strain gauge load cells placed under the bed legs (bed sensor vital sign monitoring system: BSS, Minebea-Mitsumi, Nagano, Japan), allowing long-term continuous automatic measurements of body weight, time spent in bed, and vital signs such as respiratory rate and pulse rate. We have already reported its accuracy for assessments of the respiratory status in healthy volunteers[10] and advanced cancer patients.[11] Its potential usefulness for long-term body weight monitoring was supported by a preliminary study in nursing home residents with severe cognitive and physical dysfunction.[12] Continuous body weight measurements with the BSS are challenging but allow continuous estimation of postoperative nocturnal weight change.

Accordingly, the aims of this study were to investigate the relationship between intraoperative fluid balance and body weight change as well as postoperative long-term and nocturnal body weight change with the load cells placed under the bed legs. The research hypothesis that body weight would increase during surgery and gradually decrease by the time of discharge from the hospital was tested in adult patients undergoing abdominal surgery.

Method

Ethics and setting

The current prospective observational study was performed at Chiba University Hospital, Chiba, Japan. Ethics approval for this study (Ethics Committee number: #3589) was provided by the Ethics Committee of Graduate School of Medicine, Chiba University, Chiba, Japan (Chairperson: Prof Masaomi Iyo) on 28 November 2019. The trial was registered prior to patient enrolment at the UMIN (University Hospital Information Network) Clinical Registry: (UMIN000040164, Principal investigator: Kyongsuk Son: Date of registration: 28 November 2019, website: https://center6.umin.ac.jp/cgi-open-bin/ctr/ctr.cgi?function=brows&action=brows&recptno=R000044319&type=summary&language=E). The article adheres to the applicable Strengthening the Reporting of Observational Studies in Epidemiology standards for observational studies.[13] Contact information for the full trial information is available at the UMIN website. The investigator fully explained the aim and potential risks of the study to each of the patients. Written informed consent was obtained from all participants in the trial.

Study population

Subject enrolment in this prospective study was started on 16 January 2020 and terminated on 31 March 2021. Inclusion criteria were adult patients (20 to 100 years old) undergoing elective abdominal surgery in our hospital. Exclusion criteria were patients undergoing emergency surgery and with artefacts or data missing in BSS measurement. The study was scheduled only if the investigators (KS, KT and YH) were available to manage the BSS system. We recruited 20 consecutive patients fulfilling both inclusion and exclusion criteria, and all agreed to participate in the study. The recruitment was temporarily stopped from April to June 2020 due to ward closures caused by COVID-19.

Perioperative management of the subjects

Patient management followed our normal routine care but with the addition of a load cell placed under each of the four-bed legs. The patients were generally admitted the day before the surgery. The last meal was taken the night before the surgery, and an oral rehydration solution (1000 ml) was prescribed as the patient's free fluid intake from 7 p.m. on the evening before surgery up to 2 h before the surgery. Anaesthesia management was not standardised for this clinical study. If indicated, an epidural catheter was inserted before induction of general anaesthesia. An initial dose of 3 ml 1% lidocaine was administered, followed by a continuous epidural infusion of $4\,ml\,h^{-1}$ of 0.125% levobupivacaine. After rapid induction of general anaesthesia, the trachea was intubated with an appropriate size of tracheal tube. For maintenance of general anaesthesia, either sevoflurane, desflurane or propofol were used in combination with remifentanil and fentanyl. An intraoperative infusion of crystalloid was administered at 4 to $6\,ml\,kg^{-1}\,h^{-1}$. A bolus of crystalloid or colloid was administered according to the amount of blood loss. In addition to a bolus administration of ephedrine or phenylephrine, noradrenaline was infused continuously at a dose of 0.03 to $0.1\,\mu g\,kg^{-1}\,min^{-1}$ at the discretion of the anaesthesiologist. After surgery, crystalloid was administered at 1 to $2\,ml\,kg^{-1}\,h^{-1}$, and the infusion rate was changed according to the urine output and blood pressure. From POD1, the infusion administration was gradually reduced or ceased as oral intake became possible.

Bed sensor vital-sign monitoring system

The bed sensor vital-sign monitoring system (a BSS prototype: MinebeaMitsumi Inc., Nagano, Japan) consists of four high-resolution strain gauge load cell sensors (C2G1-50K-A: rated output $2.0 \pm 0.2\,mV\,V^{-1}$, rated capacity 50 kg, total error 0.02%R.O., MinebeaMitsumi Inc., Nagano, Japan) placed under the legs of a medical bed (KA9801A, Paramount Bed Co. Ltd., Tokyo: weight 138 kg, length 2156 mm, width 960 mm, height 250 to 600 mm). The four sensors assure one gram resolution for 100 kg. The precise mechanism of the BSS system is explained in our previous reports.[10,11] A data logger is connected to the load cells processes and analyses the load cell signals. The BSS system continuously captures the total weight on the sensors, body weight, and movements on the bed, including body movements and cardiorespiratory-related centroid shifts. Each load cell sensor independently measured weight, and the digital load cell signal was sampled at 200 Hz and filtered for each load cell before decimation (10 Hz) for data analyses. Using the 10 Hz data, the BSS system automatically selected data with no or only small body movements, and a single median value for each 1 h clock period was determined for analysis in this study. The weight of the bed and items on the bed were calibrated to zero before the patient lay on the bed. The patient's body weight (BSS-BW) was measured as an additional weight to the calibrated zero weight. Although the sensor specification of the load cells ensured the accuracy of the weight measurements, and we have described long-term weight changes in elderly patients in a nursing home,[12] we have not validated the accuracy of the continuous body weight measurements in hospitalised surgical patients. A patient leaving the bed was detected by the loss of body weight. When the bed was empty for more than a minute, the datalogger software automatically recalibrated the BSS-BW to zero. The magnitude of body movements on the bed was quantified by the acceleration of the weight change as an activity index (ACI: $g\,s^{-2}$). The ACI was calculated for daytime and night-time. The ratio between daytime ACI and night-time ACI was used for assessing the circadian rhythm. The ACI ratio decreases with more night-time activity or less daytime activity. Total time in bed and bed leaving frequency were also measured as indicators of activity in each 24-h period. BSS measurements were performed throughout the hospital stay, and BSS data from the day before surgery to the 6th POD were used for analyses in this study. For each day, BSS data were divided into three periods (AM 06:00 to 14:00; PM 14:00 to 22:00; Night 22:00 to 06:00). The means of the median values determined for each hour during these periods were calculated for each BSS variable when there were minimal body movements: body movements were part of the ACI data. To ensure there was minimal contamination of the body weight by artefacts from movement, median night-time BSS-BW data were plotted as a function of time (hour), and the slope of the linear regression line denoting estimated nocturnal body weight change rate ($g\,h^{-1}$) was obtained.

Primary and secondary outcomes and sample size determination

We expected an increase of body weight immediately after surgery, reflecting fluid balance during the surgery. Accordingly, the primary outcome of this study was to test the hypothesis that the body weight (primary variable) would increase during surgery and gradually decrease by the time of discharge from the hospital. The primary variable (BSS-BW) was measured by the BSS. In addition to nightly BSS-BW measurements on the day before surgery, the day of surgery, and on the 1st to 6th PODs, the BSS-BW was measured one hour before the surgery and immediately after surgery. Intraoperative BSS-BW change was calculated by the difference of BSS-BW before and immediately after surgery. Causes of the BSS-BW deviation include load cell misplacement leading to underestimation of true body weight; any materials placed temporally on the bed without weight calibration, continuous body movements and interventions to the patients by the nurses and medical staff lead to overestimation of body weight. Body weight (Scales-BW) was also measured at the time of admission on the day before surgery by the patient standing on scales (DST-210S, MURATEC-KDS CORP., Kyoto, Japan). Cases with preoperative BSS-BW deviating by more than 10% from the preoperative Scales-BW were excluded. In the case of postoperative hourly BSS-BW values, if they deviated from the preceding day's value by more than 10%, they were not used in the analysis. As a secondary outcome of this study, the association between intraoperative changes of BSS-BW and fluid balance was assessed. Intraoperative cumulative fluid balance (secondary variable) was calculated from the intraoperative fluid volume, blood loss, urine volume and other out-balances. To compare body weight change, the fluid balance was expressed as gram units by converting one milliliter of fluid volume to 1 g of fluid weight. Since there was not enough evidence to calculate the sample size for the primary outcome and continuous measurement of perioperative body weight, the sample size for this study was determined to assess the secondary outcome. To detect a correlation coefficient greater than 0.7, assuming $\alpha = 0.05$ (two-tailed) and $\beta = 0.8$, at least 14 patients are required (SigmaPlot 12.0; Systat Software Inc., Point Richmond, CA). Considering estimating error and possible dropouts, we planned to recruit 20 patients in this study.

Statistical analysis

Continuous data are presented as mean ± SD when normality was confirmed by the Shapiro–Wilk test and as median [interquartile range] for nonparametric data. No frequencies were shown because of the small number of categorical variables. No missing value treatment was planned. We tested the primary hypothesis with a linear mixed effect model for BSS-BW (primary variable) accounting for time effect. Changes of other BSS variables during perioperative period were also analysed with the linear mixed effect model. Pearson product-moment correlation analysis was performed to assess the association between BSS-BW balance and fluid balance (secondary hypothesis). P values were two-sided, and a value of P less than 0.05 was considered statistically significant. All statistical analyses were performed using SAS software version 9.4 (SAS Institute, Cary, North Carolina, USA) and SigmaPlot 12.0 (Systat Software Inc., Point Richmond, CA, USA).

Results

A total of 20 patients who fulfilled the inclusion and exclusion criteria were recruited, and continuous BSS monitoring was started. Figure 1 shows the flow chart for the patients in the study. The technical failure arose because the power was not switched on immediately after arrival in the ward for two patients. One patient needed ICU management after surgery. Preoperative BSS-BW values were greater than 10% of the preoperative Scales-BW in three patients. Background characteristics and intraoperative management data in the remaining 14 patients are shown in Table 1. An example of the weight data collected can be seen in Supplementary Fig. 1, Body weight change demonstration, http://links.lww.com/EJAIC/A52.

Feasibility of body weight measurements with the load cells under the bed-legs during hospital stay for minor abdominal surgery

The time in bed without body movements suitable for BSS variable measurements was longer during night-time than during the daytime: 85 ± 4 versus 64 ± 4% of total time in bed, $P < 0.001$) while the BSS vital sign monitoring, including body weight measurements, were possible for more than 50% of the daytime and night-time periods. Figure 2a presents the results of the relationship between BSS-BW before surgery and body weight measured by the scales on admission, and Fig. 2b a Bland–Altman plot for 14 patients who succeeded in BSS-BW measurements with minimal body movements. The slope of the linear regression was near 1.0 (1.03), and the association was highly significant between the two body weight measurement methods (Pearson's R value = 0.997, $P < 0.001$). Fixed bias and standard deviation of the differences were 1.3 ± 1.1 kg with limits of agreement −0.9 to 3.4 kg. No systematic proportional bias was indicated.

Table 1 Patient characteristics, anaesthesia management and postoperative course

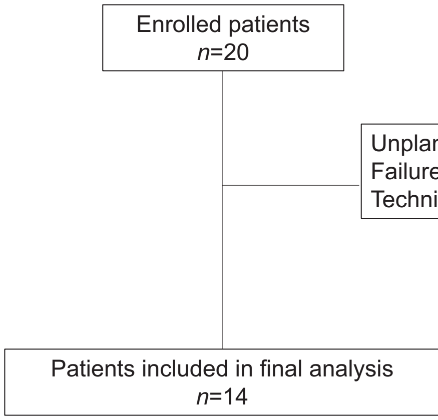
Patient characteristics (n = 14)	
Sex (male, female)	(10, 4)
Age (years)	71 [61 to 76]
Height (cm)	162 [156 to 172]
Body weight (kg)	60.3 [52.8 to 69.4]
BMI ($kg\,m^{-2}$)	23.5 [21.3 to 25.7]
Preoperative BSS-BW (kg)	
ASA-PS:1, 2	5, 9
Hypertension	7
Chronic renal dysfunction	1
Aortic stenosis	1
Diabetes mellitus	3
Hyperlipidemia	1
COPD	1
Obstructive sleep apnoea	1
Myelodysplastic syndromes	1
Surgery	
Laparoscopic colorectal resection	6
Laparoscopic intestinal resection	1
Da Vinci colorectal resection	4
Da Vinci partial gastrectomy	2
Partial gastrectomy	1
Surgical duration (min)	232 [164 to 308]
Anaesthesia	
Anaesthesia duration (min)	300 [224 to 370]
Crystalloid infusion (ml)	1710 [1525 to 2000]
Colloid infusion (ml)	0 [0 to 0]
Urine output (ml)	217 [155 to 294]
Blood loss (g)	10 [5 to 143]
Fluid balance (ml)	1610 [1176 to 1879]
Immediate postoperative BSS-BW (kg)	63.4 [55.3 to 71.3]
Intraoperative BSS-BW change (g)	2500 [2030 to 3730]
Postoperative course	
Last POD of fluid infusion:0,1,2,3,4,5,6, (n)	7, 2, 2, 0, 4, 1, 0
Postoperative complications: yes, no, (n)	1, 13
Bleeding at anastomosis	1
Hospital stay (days)	10 [9 to 13]

Variables are expressed as medians [IOR] or n. ASA-PS, American Society of Anesthesiologists-physical status; BSS, bed sensor vital sign monitoring system; BSS-BW, body weight measured by the BSS system; COPD, chronic obstructive pulmonary disease; POD, postoperative day.

Results of the primary and secondary outcomes

Figure 3a presents daily changes of estimated BSS-BW (primary outcome) during the hospital stay with the mixed effect model analysis. BSS-BW increased from 60.6 kg (95% CI, 54.4 to 66.8 kg) to 63.3 kg (95% CI,

Fig. 1 Flow chart of patients.



57.1 to 69.5 kg) immediately after surgery ($P < 0.001$), corresponding to a 2.7 ± 1.3 kg (5%) increase from preoperative BSS-BW. BSS-BW returned to the preoperative level within 3 days after surgery. Notably, BSS-BW on the 6th POD was significantly below the preoperative level by 1.8 ± 1.8 kg (3%) ($P < 0.001$). Figure 3b represents the estimated nocturnal BSS-BW change rate with the mixed effect model analysis. Although BSS-BW change rate was negative before surgery, it was positive during the night of the surgery, indicating the progressive increase of BSS-BW. The BSS-BW change rates in fluid infusion nights (24 nights) were positive and significantly greater than those of no fluid infusion nights (70 nights) (Fig. 3c). Figure 4 presents the relationship between intraoperative cumulative fluid balance (secondary outcome) and BSS-BW increase immediately after surgery. The Pearson product-moment correlation analysis indicates no association between them ($P = 0.178$). The intraoperative BSS-BW increase was significantly greater than the intraoperative fluid balance by 1.2 ± 1.2 kg: average BSS-BW 2.7 ± 1.3 kg *versus* additional fluid weight 1.5 ± 0.4 kg, $P < 0.001$. Seven out of 14 patients (50%) gained more than 2.5 kg weight.

Perioperative changes of day and night patients' activity

Figure 5 presents daily changes of estimated total bedtime, daytime bed leaving frequency, ACI during daytime and nighttime and ACI ratio with the mixed effect model analysis. Although the patients stayed in bed for 20.5 ± 2.8 h in a day during the hospital stay, daytime ACI

Fig. 2 Correlation between weight measurement by contact-free monitoring and conventional measurement. The correlation between body weight (body weight measured by the bed sensor vital sign monitoring system) measured with load cells placed under the legs of the bed with the patient lying in bed the night before surgery and body weight measured in the standing position on admission is shown on the left. Bland–Altman plots for these results are shown on the right.

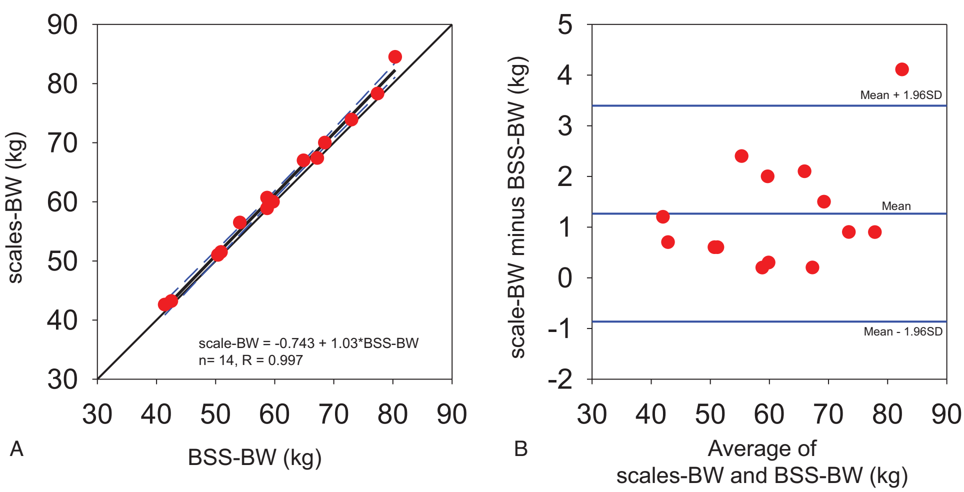
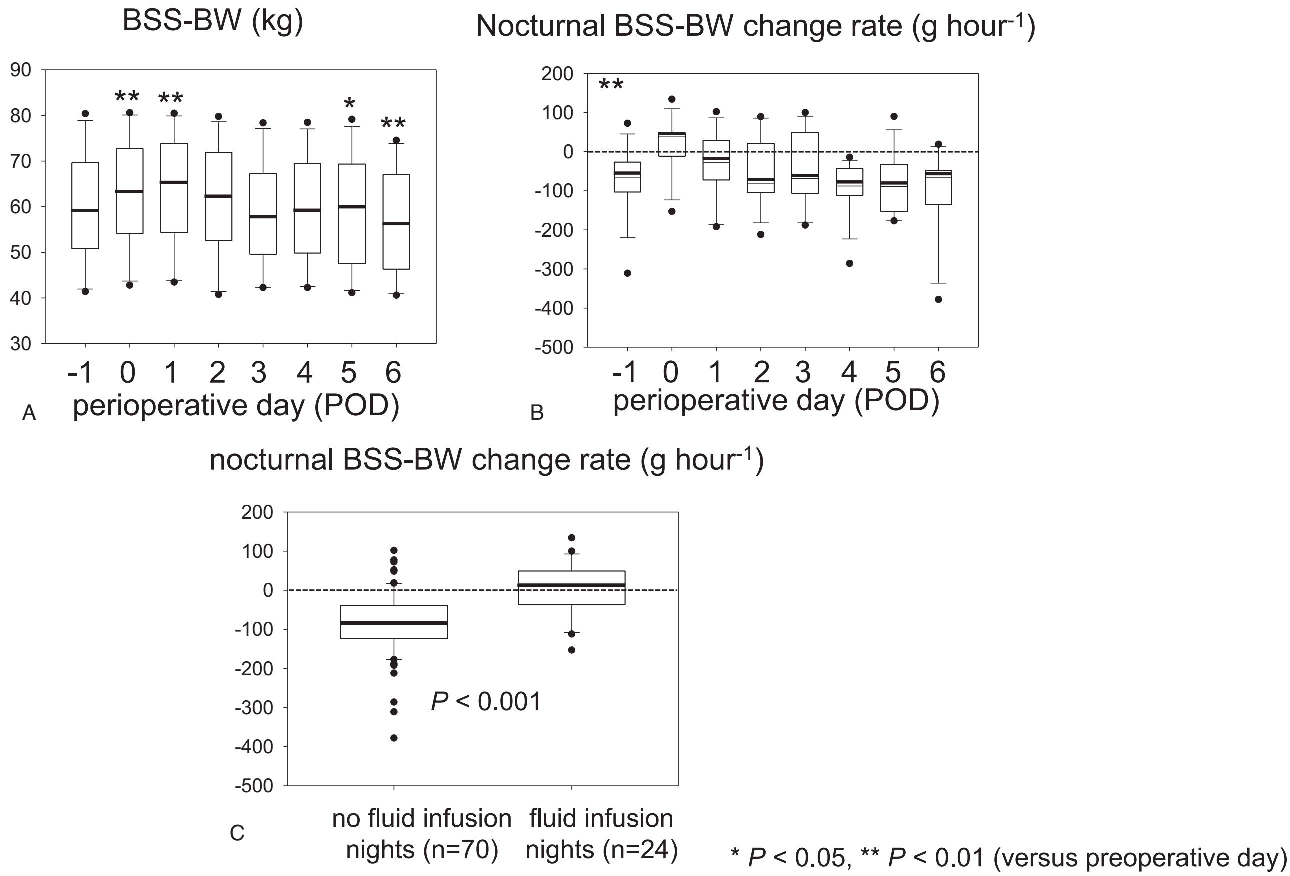


Fig. 3 Perioperative body weight change and nocturnal body weight change rate. Perioperative changes of estimated body weight measured by the bed sensor vital sign monitoring system (primary outcome) (a) and nocturnal body weight measured by the bed sensor vital sign monitoring system change rate (b) during the hospital stay with the mixed effect model analysis. The difference in nocturnal body weight measured by the bed sensor vital sign monitoring system change rate with and without fluid infusion (c). BSS-BW, body weight measured by load cells under the bed legs with the patient lying in bed during the first perioperative night; POD, postoperative day.



was significantly greater than the night-time ACI (5343 ± 2077 *versus* 2721 ± 1389 g s^{-2}, $P < 0.001$). Furthermore, ACI ratio was always greater than 1.0, indicating the presence of diurnal variation of ACI. However, they stayed on bed for a whole day with significantly smaller daytime ACI and reduced bed-leaving frequency on the operation day and the first POD. This state of daytime immobilisation recovered after the POD2, evidenced by recovering of daytime bed leaving frequency and daytime ACI. At the same time, however, night-time ACI significantly increased on the PODs 2, 3 and 4, possibly reflecting the occurrence of sleep disturbance. ACI ratios on POD0, POD4, and POD5 (2.10 ± 1.30, 2.06 ± 1.16 and 2.12 ± 0.80, respectively) were significantly smaller than the preoperative ACI ratio (3.04 ± 1.17) ($P < 0.05$).

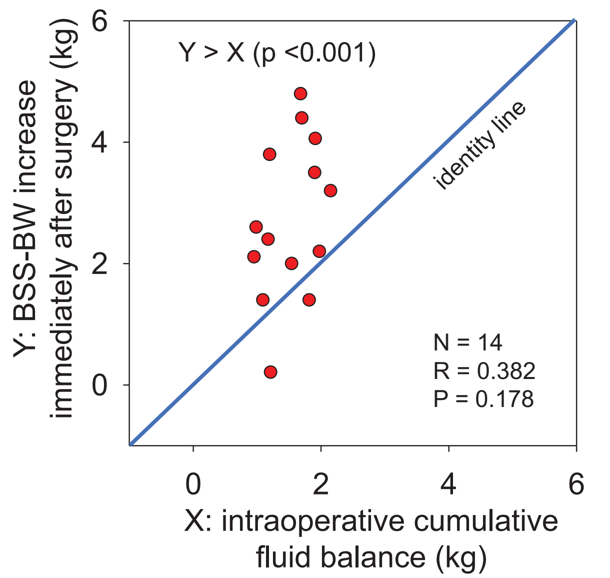
Discussion

In this prospective observational study, we noted the relationship between intraoperative fluid balance and body weight change as well as postoperative long-term and nocturnal body weight change with the BSS load cells placed under the bed legs in adult patients undergoing elective abdominal surgery. First, body weight increased by 2.7 ± 1.3 kg immediately after surgery (5% increase from the preoperative body weight), which was significantly greater than intraoperative fluid balance 1.5 ± 0.4 kg ($P < 0.001$). Second, body weight returned to the preoperative level on POD3 and further decreased to 97% of the preoperative body weight in a week. Third, compared with preoperative daytime status, patients stayed in bed longer with less frequent bed-leaving and smaller body motion in bed until POD3. Fourth, compared with preoperative night-time status, patients had greater body motion in bed leading to smaller diurnal variation of the body motion strength in bed after POD4.

Roles of fluid balance and body weight change in perioperative fluid managements

In agreement with the previous studies assessing postoperative fluid balance and body weight change,[6–9]

Fig. 4 Correlation between intraoperative cumulative fluid balance and body weight measured by the bed sensor vital sign monitoring system increase immediately after surgery. There was no significant correlation between intraoperative cumulative fluid volume (*X*: secondary endpoint) and body weight measured by the bed sensor vital sign monitoring system increase immediately after surgery. BSS-BW, body weight measured by contact-free unconstraint load cells under the bed legs in a lying posture during perioperative night.



intraoperative fluid balance was not correlated with changes of body weight before and after abdominal surgery in this study. Fluid balance can be updated in real-time after surgery, providing practical information for adjustments of infusion rate and volume. However, among the elements of fluid balance calculation, the amount of bleeding is difficult to measure due to possible uncounted blood loss remaining in and leaking outside the body (Fig. 6).

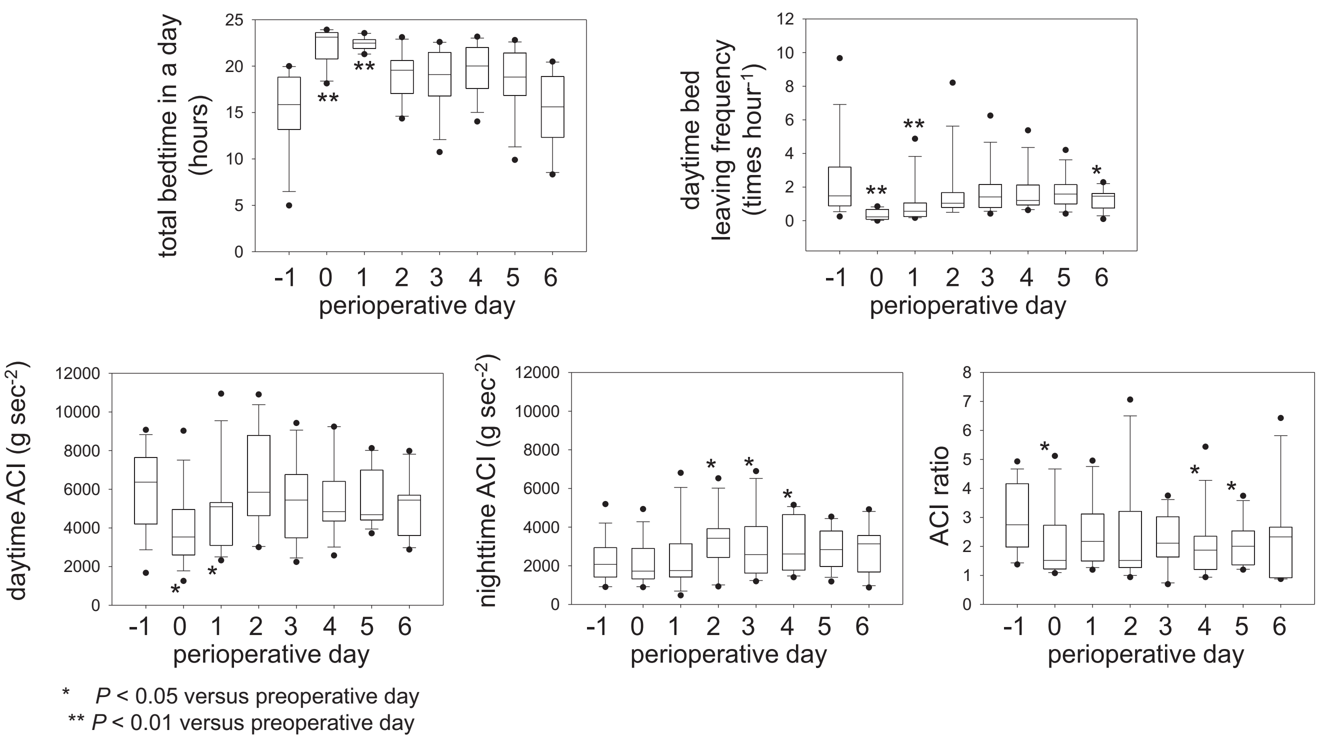
Body weight measurements are not commonly performed immediately after surgery because of the difficulty patients have in standing on weighing scales and the necessity for an expensive weighing bed for immobilised patients.[12] Therefore, the value of perioperative body weight measurements is unclear at present. In this study, intraoperative body weight changes ranged from 0.2 to 4.8 kg, while the mean weight gain of 2.7 kg was significantly greater than the intraoperative fluid balance by 1.2 kg on average. Intraperitoneal lavage was performed with 1000 ml to 1500 ml physiological saline, which was then aspirated, but residual saline probably remains within the abdominal cavity. This residual saline is absorbed through the peritoneum and may contribute to the persistent postoperative weight gain,[14,15] but it does not explain all the weight gain. In addition, this study also lacked data on the weight of the excised tissues, which could be another factor contributing to the differences. Further study is needed to determine the, as yet, unknown causes for the difference in increased body weight and fluid balance (Fig. 6). This study was not designed to validate the reliability of BSS-BW measurements, and it is not possible to determine which of the fluid balance or body weight is more accurate or more clinically useful. However, body weight and fluid balance should complement each other, as they assess different aspects of the human body, provide different physiological and pathophysiological information, always remembering that both measurements may not always be accurate.

Clinical significance of postoperative body weight measurements

The observed pattern of body weight change after POD1 was slightly different from the patterns reported in previous postoperative body weight studies.[1,8,16] Labgaa *et al.*[16] reported clinically meaningful differences in body weight changes after liver surgery between patients with and without major postoperative complications (4.2 versus 2.3 kg, respectively), while the weight gain peaked on POD3 in all patients. When standard fluid administration was performed, body weight increased by approximately 4 kg and peaked on POD2 or POD3 in the patients undergoing major abdominal surgery.[1,6] In this study, patients were managed with intraoperative infusion rates that exceeded the ERAS protocol,[17] however, the fluid volume itself, which could affect the outcome of the study, was similar to the restricted infusion group in other studies due to the short duration of the surgery.[18] We believe that both the severity of weight gain and the pattern of body weight change after surgery, along with information about intake and loss, may be markers for the optimisation of postoperative fluid and nutritional managements.

To our knowledge, this study is the first to document nocturnal body weight loss and circadian body weight changes in postoperative patients. Theoretically, body weight in a subject resting on the bed decreases during the night due to insensible water loss[19] and energy expenditure, assuming no fluid administration or urination.[20–22] Postoperative fever and persistent systemic inflammation, if present, may increase both insensible water loss and energy expenditure and accelerate nocturnal weight loss. While the positive balance of daytime fluid and energy intake usually compensates for the nocturnal weight loss,[22] our results indicate the daytime positive balance was not enough to maintain body weight. Postoperative malnutrition, as well as increases in daytime resting and immobilisation, may explain the significant weight reduction on the POD6 in our study.[23–25] While the progressive weight reduction during the postoperative period from the relatively constant nocturnal weight loss observed in this study is interesting, its pathophysiological meaning and utility in clinical practice need to be investigated in future studies. In particular, this perspective is important since elderly

Fig. 5 Perioperative changes in daytime and night-time activity measurements by bed sensor vital sign monitoring system. Perioperative changes in estimated total time in bed, frequency of daytime withdrawal, daytime and night-time activity index, and activity index ratio based on mixed-effects model analysis. Compared with the preoperative period, total bed time and bed leaving frequency decreased significantly in postoperative days 0 and 1, and activity index ratio decreased in postoperative days 0, 4 and 5. In particular, postoperative days 4 and 5, in which the activity index did not decrease during the day, indicated an increase in nighttime activity. BSS, bed sensor vital sign monitoring system; ACI; activity index: acceleration of the abrupt weight shift on the load cell sensors placed on the bed legs predominantly caused by patient's body movements on the bed. Pe: preoperative day, OP: operative day, POD: postoperative day.



patients successfully treated by the surgery often develop sarcopenia and frailty, which are known to be associated with shorter long-term survival.[26,27]

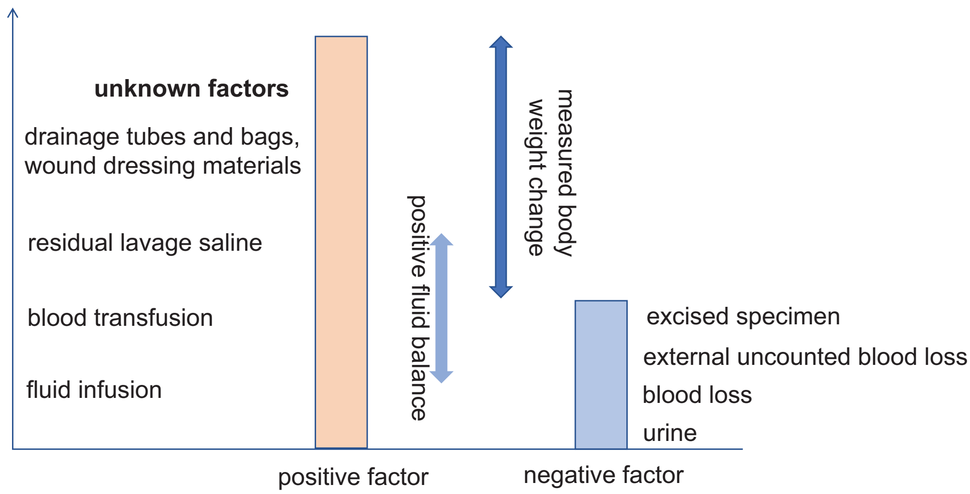
Clinical implications of perioperative monitoring of day and night activity patterns

We found an increase of nocturnal physical activity on POD2 and POD3, suggesting the occurrence of sleep disturbance. The activity index measured by the BSS has the potential to detect circadian rhythm and sleep disturbance by comparing daytime and night-time physical activity levels. This new parameter may have some clinical value for the management of postoperative sleep, as sleep disturbance has been reported as a risk factor for postoperative delirium.[28] Previous studies have reported in-hospital and postoperative recovery of daytime physical activity with a wrist-worn three-dimensional accelerometer.[29–31] Hussey *et al.* documented progressive recovery of light-intensity activity from POD1 to POD5 in patients undergoing oesophagectomy, but they did not measure the physical activity on preoperative and operative days.[29] Other studies reported that moderate and vigorous physical activity did not return to the preoperative level for several months after the surgery,[30,31] while the recovery was improved by early mobilisation programmes and physiotherapy.[30] In this study, BSS system revealed a lower daytime bed leaving frequency even on POD6 than on the preoperative day, in agreement with the previous studies (Fig. 5). It was a surprise to us that patients were in the bed for more than 20 h a day throughout the hospital stay. Such an immobilisation period has the potential to increase the risk of muscle atrophy and sarcopenia,[32] suggesting that the structure and organisation of the hospital and wards need to be redesigned to facilitate active mobilisation during admission. Activity monitoring is a new research tool that has never been used before and allows for long-term monitoring beyond the use of postoperative patients.

Strength and weakness of the study

The strength of this study was the use of load cell sensors under the bed-legs. These sensors do not require the patient to get out of bed to stand on scales, nor are they attached to the patients and so the latter are unconstrained. This is the first time that patients undergoing abdominal surgery have had continuous measurements of multiple vital signs, including body weight, for a week

Fig. 6 Schematic illustration of some factors responsible for intraoperative body weight change. Fluid balance and measured weight changes are different, although complementary and the factors responsible overlap. The relative contribution of these factors is unknown.



after surgery while they are unconstrained. The BSS continuously extracts and uses signals for body weight measurements free from unstable body movement and repeats automatic zero calibration whenever the subject leaves the bed, thus cancelling the weight of extra-items placed on the bed. Although there was only a small bias in the Bland–Altman plot for the BSS-BW versus the Scales-BW (Fig. 2), the development of sophisticated algorithms for more reliable automatic body weight measurements throughout the day is necessary in the future. Simultaneous measurements of physical activity in the bed with weight acceleration signals could differentiate the strength of body movements and the wake/sleep status, similar to a wearable accelerometer.[33] However, the BSS system cannot be clinically implemented without cost. Future studies need to test whether the use of the BSS system improves both clinical outcomes and cost-effectiveness over conventional patient care with intermittent vital sign monitoring by nurses.

However, this study has several major limitations. First, any patient care materials and/or personal belongings placed on the bed after calibration and producing less than a 10% increase of preoperative body weight might have resulted in erroneous body weight estimation. A relatively large number of patients (6/20) were excluded from the final analyses mainly due to technical reasons. Since these technical errors were minimal during the night-time, we used nocturnal body weight data to monitor the weight changes. Clearly, the current calibration algorithm needs to be improved to minimise these technical errors. Second, we did not compare the accuracy of the BSS-BW with other gold standard techniques commonly used in ICU. Third, it is difficult to generalise the results of this study because of the limited patient population with only a small variation in the surgical procedures. Patients undergoing more invasive surgery or with severe preoperative complications or with a high BMI and paediatric patients might have different results. Perioperative patient monitoring by BSS has not been validated by other standard methods. Further study is needed on the cut-off value since a deviation of 10% or more from the Scale-BW or the preceding day's value is defined as an exclusion criterion. This observational study was not designed to explore pathophysiological mechanisms of perioperative body weight changes. A clinical study assessing both the risk of sarcopenia and weight change may provide clinically meaningful findings. Furthermore, we consider clinical trials testing and validating the clinical significance of perioperative body weight measurements are necessary.

In conclusion, using sensitive load cells placed under the bed legs revealed changes in perioperative body weight and physical activity throughout the hospitalisation period. Postoperative fluid and nutrition management strategies are potentially new treatment options guided by continuous weight monitoring during the perioperative period.

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Conflicts of interest: the current study used data obtained during collaborative research between Chiba University and MinebeaMitsumi Inc. SI, as a head of the Department of Anesthesiology, Chiba

University received scholarship donations from MinebeaMitsumi Inc. SI is one of the inventors of the vital sign monitoring system used in this study.

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