Three-dimensional visualization system is one of the factors that improve short-term outcomes after minimally invasive esophagectomy

Kudo, Takuya ; Oshikiri, Taro ; Takiguchi, Gosuke ; Urakawa, Naoki ; Hasegawa, Hiroshi ; Yamamoto, Masashi ; Kanaji, Shingo ; Matsuda,…

(Citation)
Langenbeck's Archives of Surgery,406(3):631-639

(Issue Date)
2021-05

(Resource Type)
journal article

(Version)
Accepted Manuscript

Title page

Manuscript Title:

Three-dimensional visualization system is one of the factors that improve short-term outcomes after minimally invasive esophagectomy.

Authors and their affiliations: Takuya Kudo, MD[1], Taro Oshikiri, MD[1], Gosuke Takiguchi, MD[1], Naoki Urakawa, MD[1], Hiroshi Hasegawa, MD[1], Masashi Yamamoto, MD[1], Shingo Kanaji, MD[1], Yoshiko Matsuda, MD[1], Kimihiro Yamashita, MD[1], Takeru Matsuda, MD[2], Tetsu Nakamura, MD[1], Satoshi Suzuki, MD[3], Yoshihiro Kakeji, MD[1]

1. Division of Gastrointestinal Surgery, Department of Surgery, Kobe University Graduate School of Medicine, Kobe, Japan
2. Division of Minimally Invasive Surgery, Department of Surgery, Graduate School of Medicine, Kobe University, 7-5-2, Kusunoki-cho, Chuo-ku, Kobe, Hyogo, 650-0017, Japan
3. Department of Social Community Medicine and Health Science, Division of Community Medicine and Medical Network, Graduate School of Medicine, Kobe University, 7-5-2, Kusunoki-cho, Chuo-ku, Kobe, Hyogo, 650-0017, Japan

Address correspondence and reprint requests to:

Taro Oshikiri, MD,

Division of Gastrointestinal Surgery, Department of Surgery, Graduate School of Medicine, Kobe University, 7-5-2, Kusunoki-cho, Chuo-ku, Kobe, Hyogo, 650-0017, Japan.

Tel: +81-78-382-5925; Fax: +81-78-382-5939; E-mail: oshikiri@med.kobe-u.ac.jp

Abstract

Purpose: Minimally invasive esophagectomy (MIE) has been increasingly used, but many reports have stated that recurrent laryngeal nerve (RLN) palsy after MIE is a major complication associated with postoperative pneumonia. Prevention of RLN palsy clearly has been a challenging task. The study aim was to determine if a three-dimensional (3-D) stereoscopic vision system can reduce the RLN palsy rate after MIE.

Methods: This was a retrospective study of MIE (McKeown esophagectomy) using a 3-D or 2-D stereoscopic vision system to treat 358 patients in the prone position between April 2010 and March 2019. The patients who underwent 3-D MIE (3-D group) or 2-D MIE (2-D group) were matched by using propensity score matching. After matching, the perioperative outcomes were compared between the groups.

Results: After propensity score matching, 154 patients were analyzed (77 patients, 3-D group; 77 patients, 2-D group). There were no significant differences in the patients' baseline characteristics in the matched cohort. There were no significant differences in the rates of pneumonia [Clavien–Dindo (C–D) grade ≥ II, 3-D vs. 2-D, 11 (14%) vs. 12(16%)], anastomotic leakage [C–D grade ≥ II, 10 (13%) vs. 18 (23%)] and mortality. The rates of left RLN palsy [C–D grade ≥ IIIa, 1 (1.3%) vs. 7 (9.1%), $P = 0.029$], right RLN palsy[C–D grade ≥ I, 2 (3%) vs. 8 (10%), $P = 0.049$], comprehensive complication index(CCI®) [8.5 vs. 14.3, $P = 0.011$] and postoperative hospital stay period (median: 25 vs. 30 days, $P = 0.034$) were significantly lower in the 3-D group than in the 2-D group, respectively.

Conclusions: In MIE, the 3-D viewing system was one of the factors that reduced postoperative morbidities such as the rates of each RLN palsy and CCI®, leading to shorter postoperative hospital stay.

Key words:

minimally invasive esophagectomy; 3-dimensional system; recurrent laryngeal nerve palsy; postoperative pneumonia

Authors' contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Takuya Kudo and Oshikiri Taro. The first draft of the manuscript was written by Takuya Kudo and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Introduction

Esophageal cancer is one of the most common cancers, with one of the highest disease-related mortality rates in the world, especially in Eastern and South African countries [1]. In Japan, esophagectomy with extended lymphadenectomy improves the patient prognosis of localized esophageal cancer but still has high morbidity and mortality rates [2]. After Cuschieri et al. first described it, minimally invasive esophagectomy (MIE) has been increasingly used worldwide because it provides magnified viewing and less body wall destruction [3], which decreases postoperative morbidity and mortality rates. On the other hand, many reports have stated that recurrent laryngeal nerve (RLN) palsy after MIE is one of the most serious complications associated with postoperative pneumonia [4]. Thus, prevention of RLN palsy is a challenging task.

The development of a 3-D stereoscopic vision system for use in laparoscopy provides direct stereoscopic depth and may improve operative speed and technical performance in laparoscopic procedures relative to those of a 2-D system [5]. A previous study found that in total gastrectomy, a 3-D laparoscopic system led to better outcomes than those of a 2-D laparoscopic system [6]. However, few reports have reported the efficacy of 3-D laparoscopic systems in MIE. The study aim was to determine if a 3-D stereoscopic vision system could help decrease perioperative complications, especially RLN palsy and postoperative pneumonia after MIE.

Materials and Methods

Patient population

This was a single-institutional propensity score-matched cohort study of patients with esophageal cancer who underwent MIE (also referred to as McKeown three-stage esophagectomy [7]) with a 2-D (2–D group) or 3-D (3–D group) laparoscopic system in the prone position at Kobe University between April 2010 and March 2019. Staging was made by esophagogastroduodenoscopy and computed tomography (CT) and/or positron emission tomography (PET) preoperatively. The diagnosis was based on the seventh edition of the Union for International Cancer Control tumor–node–metastasis (TNM) cancer staging system [8]. For clinical (c)-Stage II/III patients, neoadjuvant chemotherapy (cisplatin/5-fluorouracil) was done. Neochemoradiotherapy was not administered for any patients. All of the surgeons were qualified in Japanese endoscopic surgical skills. They had done more than 30 MIE cases, which is a well-evidenced threshold that the surgeons finished the implementation of MIE procedures [9, 10]. Thoracoscopic esophagectomy was performed only by four surgeons who were qualified in Japanese endoscopic surgical skills [11]. The eligibility criteria consisted of age > 20 years, cT1–3 and cN0–3 diseases, upper mediastinum lymphadenectomy and posterior mediastinal route using a gastric conduit. The patients with total pharyngo–laryngo dissection, jejunal interposition or using a gastric conduit without posterior mediastinal route were excluded.

This study was approved by the Ethics Committee of Kobe University and institutional review board. Informed consent was obtained from all patients who met the inclusion criteria.

Methods

The 3-D group underwent surgery using the 3D/high-definition (HD) system (Olympus Corporation, Tokyo, Japan) equipped with a flexible 0° direction of view and a 10-mm-diameter laparoscope, and 3-D glasses were used by both the surgeons and assistants. The 2-D group underwent surgery using the 2D/HD system (Olympus Corporation, Tokyo, Japan) equipped with a 30° direction of view and a 10-mm-diameter laparoscope. The surgical methods used for the two groups were the same. Most of the 2-D patients underwent MIE up to 2014, and the 3-D patients underwent MIE starting in 2014 after we deployed the 3-D system for use in thoracic MIE procedures in 2014.

Thoracic procedure

Before the procedure, a single-lumen tracheal tube was inserted into the trachea, and a blocker was inserted into the right bronchus for one-lung anesthesia in order to permit easy retraction of the trachea. All thoracic procedures were performed in the prone position. Five ports (5-mm or 12-mm) were inserted in the third intercostal space (ICS) behind the midaxillary line; the fifth, seventh, and ninth ICS on the posterior axillary line; and the eighth ICS on the midaxillary line. Port of the ninth ICS on the posterior axillary line was usually used for the thoracoscope [12]. Number of lymph node dissection areas were 2 or 3 fields.

During upper mediastinal lymphadenectomy, we used scissors, not energy devices, to dissect the tissues including lymph nodes surround RLN because of avoiding heat damages to nerves.

Abdominal procedure

The abdominal procedure was essentially performed as a laparoscopic gastric mobilization to form a gastric conduit. Abdominal lymph nodes were dissected included those surrounding the left gastric pedicle and the celiac trunk. After the entire isolated thoracic esophageal specimen with dissected lymph nodes was pulled out through the hiatus of esophagus, we made a gastric conduit of 3–4 cm in diameter. To estimate the gastric conduit's blood supply, patients was injected 2.5 mg indocyanine green (ICG) as a bolus, then we monitored ICG fluorescence images through real-time navigation tool "Photodynamic Eye™ (Hamamatsu Photonics K.K.)" [13]. After examination of ICG, we raised conduit in the posterior mediastinal route.

Neck procedures

The site of the anastomosis was the neck. The cervical lymph nodes dissection was performed by a collar incision. The standard procedure was esophagectomy with 3-field lymph node dissection. But the decision to perform supraclavicular lymphadenectomy depended on patient co-morbidities, age, tumor location and clinical stage. Supraclavicular lymphadenectomy was likely omitted in patients with lower esophageal tumors, cT1 tumors and cN0 tumors. If supraclavicular lymph nodes were diagnosed as metastasis by preoperative CT or PET, 3-field lymph node dissection was done.

Outcomes

Evaluation of the postoperative clinical course

The operative times of both entire and thoracic procedure, retrieved lymph nodes dissection of the thoracic procedure, estimated operative blood loss, transfusion, and postoperative hospital stay were compared between the 3-D and 2-D groups. We also analyzed postoperative complications, including left and right RLN palsy, pneumonia after operation, and leakage. The severity of complications was using the Clavien–Dindo (C–D) classification system [14] and the comprehensive complication index (CCI®) , which is estimated severity of total complications based on C-D classification, ranging from 0 (uneventful course) to 100 (death) [15, 16]. To diagnose RLN palsy, all patients were referred to otolaryngologists of the same institution on postoperative day 7 and examined vocal cord mobility with a flexible laryngoscope by them. Postoperative pneumonia was diagnosed as the presence of clinical manifestations of pneumonia or bronchopneumonia by radiological tests including CT scan and positive of sputum culture during 2 weeks after the operation. We diagnosed anastomotic leakage according to the changes of the drainage fluid character, CT scan findings and results of esophagogastroduodenoscopy. RLN palsy and postoperative pneumonia were the primary clinical endpoints.

Statistical analysis

To remove bias from all observed covariates, patients in both 2-D and 3-D groups were matched with the propensity score (PS). The PS for individuals was calculated with the covariates of age, sex, location of tumor, invasion depth of tumor, lymph node metastasis, neoadjuvant chemotherapy, and fields of lymph node dissection. Using the PSs, each 3-D group patient were sequentially matched to a 2-D group patient with a 1:1 nearest neighbor matching algorithm without replacement. To prevent poor matches, a caliper of 0.20 of the standard deviation of the logit of the propensity score was used [17].

Analysis of the statistical differences between the two groups were performed by the χ^2 test, the Student's *t*-test or the Mann–Whitney *U*-test, as appropriate. All *P* values < 0.05 were considered as indicative of statistical significance. All statistical computations, including propensity score matching, were performed by using JMP® 11 (SAS Institute, Cary, NC, USA).

Evaluation of the learning curve effect

To analyze the learning curve effect in the thoracic procedure time of each surgeon, we used the 5-patient simple moving average (5-SMA) curve and the cumulative sum (or CUSUM) control chart in the 2-D group after matching. Both analyses were widely used to estimate the learning curve in the surgical procedure [18, 19]. The moving average is the analysis by creating a series of cases. It smoothes out the fluctuation and shows the trends. If the curve shows the decreasing trends, it suggests the surgeon doesn't finish the leaning curve. We use the order 5 in this study.

CUSUM can also detect changes in sequential cases. We defined CUSUM (Sn) $= \Sigma (X_i - \mu)$; X_i is the thoracic procedure time of each surgeon; μ is the mean of each surgeons' thoracic procedure time. If the surgeon doesn't finish the learning curve, the chart goes up with positive values. If the surgeon finishes the learning curve, X_i values move around each surgeon's mean, then CUSUM values go up and down randomly.

Results

Patient characteristics

Total 358 patients were eligible to this study. Of these, 157 and 108 patients underwent surgery using the 2-D system or 3-D system, respectively. After propensity score matching, 154 patients were included in the analysis (77 patients in each group) (Fig. 1). Table 1 shows the baseline characteristics of the patients in each cohort and no significant differences in these characteristics compared between each 2-D and 3-D groups in the matched cohort (Table 1).

Outcomes

Table 2 summarized the perioperative outcomes. The operation time, both total and thoracic procedure, counts of retrieved mediastinal nodes, intraoperative transfusion had not statistical significances. The amount of intraoperative blood loss was lesser in the 3-D group than in the 2-D group [3-D median, 140 (range, 0–698) mL; 2-D median, 260 (range, 0–1160) mL; $P = 0.0003$] (Fig. 2a). Regarding the postoperative complications, postoperative pneumonia with or without any RLN palsies was lesser in the 3-D group than in the 2-D group, but not statistically significant(C–D grade ≥ II, 13% vs. 23%, respectively; $P = 0.09$). The incidence of left RLN palsy was significantly fewer in the 3-D group than in the 2-D group (C-D grade ≥ IIIa, 1% vs. 9%, respectively; $P = 0.029$). The incidence of right RLN palsy was also significantly fewer in the 3-D group than in the 2-D group (C-D grade ≥ I, 3% vs. 10%, respectively; $P = 0.049$). The comprehensive complication index is significantly lower in the 3-D group than in the 2-D group (average [95% C.I.], 8.5 [5.4-11.7] vs. 14.3 [11.1-17.4]; $P = 0.011$).The postoperative hospital stay days of the 3-D group were significantly shorter than those of the 2-D group [3-D median, 25 days (range, 10–141 days); 2-D median, 30 days (range, 17–150 days); $P = 0.034$] (Fig. 2b). There were no significant differences in anastomotic leakage (C-D grade ≥ II, 14% vs. 16%, respectively; $P = 0.82$) and postoperative mortality within 30 days after surgery (each one case (1.3%)) between the two groups (Table 2).

Moving average and CUSUM analysis

The thoracic procedures were performed four surgeons (surgeon A, B, C and D). The thoracic procedure time of every patient, 5-SMA chart and CUSUM chart were plotted in Figure 3. The mean time of each surgeon is shown as follows: A was 291.5 ± 32.6 min (n = 26); B was 336.2 ± 50.8 min (n = 9); C was 332.1 ± 56.3 min (n = 16); D was 323.3 ± 68.7 min (n = 26). There was no decreasing tendency of each 5-SMA curve. Using the CUSUM chart, there was no peak point of each surgeon in 2-D and 3-D system.

Discussion

Our results showed that the 3-D system was associated with less intraoperative blood loss, decreased rate of each RLN palsy, CCI®, and shorter postoperative hospital stay. According to European Association of Endoscopic Surgery (EAES) consensus in 2018 for 3-D system [20], 3-D system can generally shorten operative time and further investigations for potential benefit on complication rates were needed. In our data, 3-D system did not shorten operative time but can reduce complications such as each RLN palsy and CCI®. Some investigators have compared 3-D versus 2-D laparoscopic systems for gastrointestinal surgery in shortening operation time and decreased blood loss because 3-D visualization may help surgeons more easily understand the anatomy that they are seeing [5, 21, 22]. However, there are few reports on the superiority of 3-D systems versus 2-D systems in MIE. Considering the difficulty of upper mediastinum dissection in MIE, it would be highly beneficial to improve the ability of surgeons to recognize the complex anatomy of the upper mediastinum, especially the area around the RLN in patients with postoperative pneumonia [4, 23]. Especially, it is important to avoid touching and stretching the RLN to prevent palsy [24]. A stereoscopic 3-D vision system should help surgeons more accurately determine the distance between the RLN, vessels, and lymph nodes visually. The benefits of a 3-D system could enable procedures that can avoid touching and stretching the RLN and thus reduce the incidence of left RLN palsy and operative bleeding. Reduction of RLN palsy, operative blood loss, and postoperative pneumonia can benefit patients, leading to shorter postoperative stays.

As supportive evidence, previous preliminary reports have stated that 3-D visualization improved the accuracy of surgeons' technique. Nishi et al. reported that 3-D monitoring improved depth perception when using forceps' relative to the horizontal and height directions in tasks within training boxes [25]. Harada et al. also showed that 3-D monitoring improved the outcomes of expert surgeons, such as shorter operative times, more accurate judging of forceps' path length, and reduced technical errors [26]. However, the benefits of a 3-D system can also be realized by novices as well. Compared with a 2-D system, a 3-D system has been shown to have a shorter learning curve to acquire skill in surgical techniques [27].

One major problem when using a 3-D laparoscopic system is the presence of stereo blindness. Stereopsis provides 3-D perception conferred by separate images taken with each eye closed that are then merged [28]. A 3-D laparoscope provides surgeons with "artificial" stereopsis viewed on a single 3-D monitor that shows merged images from two separated cameras that are viewed through polarized glasses [29]. However, some surgeons cannot recognize the artificial images on a 3-D monitor as "3-D" images, which is called stereo blindness. Fergo et al. showed that the prevalence of stereo blindness in medical doctors was 9.7%. Stereo-blind surgeons have a potential risk of performing worse than surgeons who are not stereo blind [30]. With technical advances, these problems may be solved in the future.

While the references [10, 11] showed the thirty cases as a threshold of the MIE learning curve, which was based on the morbidity, we analyzed the learning curve based on the thoracic procedure time. Moving average and CUSUM are both well-known methods to estimate the learning curve [18, 19]. Simple moving average(SMA) can show the chronological changes of operating time. However, the SMA chart sometimes goes flat, and it remains unclear where the turning point of the learning curve. Yet CUSUM is a sequential analysis to detect the out-of-control signals. If the surgeon doesn't finish the learning curve, so the CUSUM chart has an increasing tendency. If the learning curve is completed during the series, the CUSUM chart goes down at some point. Adding to SMA, CUSUM can show the consistent quality of procedures if the CUSUM values stay within the control ranges. According to 5-SMA and CUSUM chart in this study, we estimated that all four surgeons had already finished the learning curve.

This study had some limitations, including its retrospective design and participation from only one center. As we discussed, the learning curve seems not to affect the results of this study. But these influences remain unclear. Moreover, the periods in which the patients in the two groups primarily underwent their surgeries were different. Furthermore, in 2015, our MIE procedures were standardized and it improved operative blood loss (376 ± 215 mL to 142 ± 87 mL, $P = 0.006$), the rate of left RLN palsy (47% to 13%, $P = 0.046$) compared between pre-standardization group and post-standardization group [13]. These chronological learning curve and standardization may influence the improvements in this study. Therefore, a prospective or retrospective study using a larger number of patients is needed to confirm our findings.

Conclusions

According to our results, 3-D laparoscopic system for MIE was one of the factors that reduced each RLN palsy and CCI®, which led to shorter postoperative hospital stays.

Declarations

Funding: The authors did not receive support from any organization for the submitted work.

Conflicts of interest/Competing interests: The authors declare that they have no conflict of interest.

Ethics approval: Approval was obtained from the ethics committee of Kobe University. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate: Informed consent was obtained from all individual participants included in the study.

Availability of data and material: The datasets generated during and analyzed during the current study are not publicly available due to medical data included participants'' personal data.

Code availability: Not applicable

Authors' contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Takuya Kudo and Oshikiri Taro. The first draft of the manuscript was written by Takuya Kudo and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

1. Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A (2018) Global cancer statistics 2018:

GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 68:394-424

2. Watson A (1994) Operable esophageal cancer: current results from the West. World J Surg 18:361-366
3. Cuschieri A, Shimi S, Banting S (1992) Endoscopic oesophagectomy through a right thoracoscopic approach. J R Coll Surg Edinb 37:7–11
4. Oshikiri T, Takiguchi G, Hasegawa H, Yamamoto M, Kanaji S, Yamashita K, Matsuda T, Nakamura T, Suzuki S, Kakeji Y (2020) Postoperative recurrent laryngeal nerve palsy is associated with pneumonia in minimally invasive esophagectomy for esophageal cancer. Surg Endosc. https://doi.org/10.1007/s00464-020-07455-1
5. Liu J, Zhou H, Qin H, Ru H, Huang J, Liang S, Mo X, Tang W (2018) Comparative study of clinical efficacy using three dimensional and two-dimensional laparoscopies in the treatment of distal gastric cancer. Onco Targets Ther. https://doi.org/10.2147/OTT.S153520
6. Kanaji S, Suzuki S, Harada H, Nishi M, Yamamoto M, Matsuda T, Oshikiri T, Nakamura T, Fujino Y, Tominaga M, Kakeji Y (2017) Comparison of two- and three-dimensional display for performance of laparoscopic total gastrectomy for gastric cancer. Langenbecks Arch Surg 402(3):493-500
7. McKeown KC (1976) Total three-stage oesophagectomy for cancer of the oesophagus. Br J Surg 63:259–262
8. Rice TW, Blackstone EH, Rusch VW (2010) 7th edition of the AJCC Cancer Staging Manual: esophagus and esophagogastric junction. Ann Surg Oncol 17:1721-1724
9. van Workum F, Fransen L, Luyer MD, Rosman C (2018) Learning curves in minimally invasive esophagectomy. World J Gastroenterol. 24(44):4974-4978
10. van Workum F, Stenstra MHBC, Berkelmans GHK, Slaman AE, van Berge Henegouwen MI, Gisbertz SS, van den Wildenberg FJH, Polat F, Irino T, Nilsson M, Nieuwenhuijzen GAP, Luyer MD, Adang EM, Hannink G, Rovers MM, Rosman C (2019) Learning Curve and Associated Morbidity of Minimally Invasive Esophagectomy: A Retrospective Multicenter Study. Ann Surg. 269(1):88-94
11. Mori T, Kimura T, Kitajima M (2010) Skill accreditation system for laparoscopic gastroenterologic surgeons in Japan. Minim Invasive Ther Allied Technol 19:18-23
12. Oshikiri T, Yasuda T, Harada H, Goto H, Oyama M, Hasegawa H, Ohara T, Sendo T, Nakamura T,

Fujino Y, Tominaga M, Kakeji Y (2015) A new method (the "Bascule method") for lymphadenectomy along the left recurrent laryngeal nerve during prone esophagectomy for esophageal cancer. Surg Endosc 29:2442-2450

13. Oshikiri T, Nakamura T, Hasegawa H, Yamamoto M, Kanaji S, Yamashita K, Matsuda T, Sumi Y, Fujino Y, Tominaga M, Suzuki S, Kakeji Y (2018) Standardizing procedures improves and homogenizes short-term outcomes after minimally invasive esophagectomy. Langenbecks Arch Surg 403: 221-234
14. Dindo D, Demartines N, Clavien PA (2004) Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 240:205-213
15. Slankamenac K, Graf R, Barkun J, Puhan MA, Clavien PA (2013) The comprehensive complication index: a novel continuous scale to measure surgical morbidity. Ann Surg 258: 1-7
16. Clavien PA, Vetter D, Staiger RD, Slankamenac K, Mehra T, Graf R, Puhan MA (2017) The Comprehensive Complication Index (CCI®): Added Value and Clinical Perspectives 3 Years "Down the Line". Ann Surg 265: 1045-1050
17. Rosenbaum PR, Rubin DB (1983) The central role of the propensity score in observational studies for causal effects. Biometrika 70:41–55
18. Choi DH, Jeong WK, Lim SW, Chung TS, Park JI, Lim SB, Choi HS, Nam BH, Chang HJ, Jeong SY (2009) Learning curves for laparoscopic sigmoidectomy used tomanage curable sigmoid colon cancer: single-institute, three-surgeon experience. Surg Endosc 23: 622628
19. Oshikiri T, Yasuda T, Yamamoto M, Kanaji S, Yamashita K, Matsuda T, Sumi Y, Nakamura T, Fujino Y, Tominaga M, Suzuki S, Kakeji Y (2016) Trainee Competence in Thoracoscopic Esophagectomy in the Prone Position: Evaluation Using Cumulative Sum Techniques. Langenbecks Arch Surg 401: 797–804
20. Arezzo A, Vettoretto N, Francis NK, Bonino MA, Curtis NJ, Amparore D, Arolfo S, Barberio M, Boni L, Brodie R, Bouvy N, Cassinotti E, Carus T, Checcucci E, Custers P, Diana M, Jansen M, Jaspers J, Marom G, Momose K, Müller-Stich BP, Nakajima K, Nickel F, Perretta S, Porpiglia F, Sánchez-Margallo F, Sánchez-Margallo JA, Schijven M, Silecchia G, Passera R, Mintz Y (2019) The use of 3D laparoscopic imaging systems in surgery: EAES consensus development conference 2018. Surg Endosc 33: 3251-3274
21. Yazawa H, Takiguchi K, Imaizumi K, Wada M, Ito F (2018) Surgical outcomes of total laparoscopic

hysterectomy with 2-dimensional versus 3-dimensional laparoscopic surgical systems. Fukushima J Med Sci 64:38-45

22. Charalabopoulos A, Lorenzi B, Kordzadeh A, Tang CB, Kadirkamanathan S, Jayanthi NV (2017) Role of 3D in minimally invasive esophagectomy. Langenbecks Arch Surg 402: 555-561
23. Cuesta MA, van der Wielen N, Weijs TJ, Bleys RL, Gisbertz SS, van Duijvendijk P, van Hillegersberg R, Ruurda JP, van Berge Henegouwen MI, Straatman J, Osugi H, van der Peet DL (2017) Surgical anatomy of the supracarinal esophagus based on a minimally invasive approach: vascular and nervous anatomy and technical steps to resection and lymphadenectomy. Surg Endosc 31:1863-1870
24. Otsuka K, Murakami M, Goto S, Ariyoshi T, Yamashita T, Saito A, Kohmoto M, Kato R, Lefor AK, Aoki T (2020) Minimally invasive esophagectomy and radical lymph node dissection without recurrent laryngeal nerve paralysis. Surg Endos. https://doi.org/10.1007/s00464-020-07372-3
25. Nishi M, Kanaji S, Otake Y, Harada H, Yamamoto M, Oshikiri T, Nakamura T, Suzuki S, Suzuki Y, Hiasa Y, Sato Y, Kakeji Y (2017) Quantitative comparison of operative skill using 2-and 3-dimensional monitors during laparoscopic phantom tasks. Surgery 161:1334-1340
26. Harada H, Kanaji S, Hasegawa H, Yamamoto M, Matsuda Y, Yamashita K, Matsuda T, Oshikiri T, Sumi Y, Nakamura T, Suzuki S, Kakeji Y (2018) The effect on surgical skills of expert surgeons using 3D/HD and 2D/4K resolution monitors in laparoscopic phantom tasks. Surg Endosc 32:4228-4234
27. Harada H, Kanaji S, Nishi M, Otake Y, Hasegawa H, Yamamoto M, Matsuda Y, Yamashita K, Matsuda T, Oshikiri T, Sumi Y, Nakamura T, Suzuki S, Sato Y, Kakeji Y (2018) The learning effect of using stereoscopic vision in the early phase of laparoscopic surgical training for novices. Surg Endosc 32:582-588
28. Whitman R (1970). Stereopsis and stereoblindness. Experimental Brain Research 10:380-388
29. Taffinder N, Smith SG, Huber J, Russell RC, Darzi A (1999) The effect of a second-generation 3D endoscope on the laparoscopic precision of novices and experienced surgeons. Surg Endosc 13:1087-1092
30. Fergo C, Burcharth J, Pommergaard HC, Rosenberg J (2016) Age is highly associated with stereo blindness among surgeons: a cross-sectional study. Surg Endosc 30:4889-4894

Figure legends

Fig. 1

After excluding 93 patients from a total of 358 patients who underwent MIE with either a 2-D or 3-D system between 2010 and 2019, 77 patients in the 2-D group and 77 patients in the 3-D group were selected after propensity score matching.

Fig. 2

a) Comparisons of intraoperative blood loss (mL) between the 2-D group and 3-D group. Middle line in the box represents the median. Lower box bounds the first quartile (Q1). Upper box bounds the third quartile (Q3). Whiskers represent the 95% confidence interval (95%CI) of the median. The median intraoperative blood loss (Q1;Q3) [95%CI] of the 2-D group was 260 mL (75 mL; 455 mL) [0–1130 mL] and of the 3-D group was 140 mL (50 mL; 232.5 mL) [0-698 mL] (P = 0.0003).

b) Comparisons of postoperative hospital stays (days) between the 2-D group and 3-D group. Middle line in the box represents the median. Lower box bounds the first quartile (Q1). Upper box bounds the third quartile (Q3). Whiskers represent the 95% confidence interval of the mean. The median postoperative hospital stay (Q1; Q3) [95%CI] of the 2-D group was 30 days (22 days; 54.5 days) [17 – 150 days] and of the 3-D group was 25 days (20.5 days; 37.5 days) [10-141 days] (P = 0.034).

Fig. 3

The plotting charts of the thoracic procedure time, 5-patients simple moving average (5-SMA) and the cumulative sum (or CUSUM) control chart. (i) shows 2-D cases and (ii) shows 3-D cases of each surgeon. Each graph (A) - (D) is corresponding to each result of surgeon A - D. The points show the thoracic procedure time (minutes); the dotted lines show the 5-SMA chart; the solid lines show the CUSUM chart. Surgeon D didn’t operate MIE in 3-D system, there is no data in Fig. 3-(ii)

Table 1 Baseline characteristics of patients treated with 2-D or 3-D laparoscopic system

	Whole cohort (n =265)			Matched cohort (n = 154)		
	2-D (n =157)	3-D (n =108(%))	*P*	2-D (n =77(%))	3-D (n =77(%))	*P*
Age, years	66 [27-82]	68 [44-82]	0.14	67 [40-79]	66 [44-82]	0.17
Sex Male/Female (%)	135/22 (86/14)	89/19 (82/18)	0.42	65/12 (84/16)	65/12 (84/16)	1.00
Location Ut/Mt/Lt (%)	30/69/58 (19/44/37)	21/52/35 (20/48/32)	0.73	13/30/34 (17/39/44)	15/36/26 (19/47/34)	0.42
Tumor depth cT 1 /2 /3 (%)	61/29/67 (39/18/43)	49/12/47 (45/11/44)	0.30	33/10/34 (43/13/44)	34/11/32 (44/14/42)	0.94
LN metastasis cN ＋/－ (%)	84/73 (54/46)	50/58 (46/54)	0.25	39/38 (51/49)	38/39 (49/51)	0.87
UICC-Staging I /II /III /IVa /IVb (%)	57/41/51/2/6 (36/26/33/1/4)	45/26/29/0/8 (42/24/27/0/7)	0.38	31/16/28/0/2 (40/21/36/3)	30/19/20/0/8 (39/25/26/10)	0.16
Histology Scc*/other (%)	146/11 (93/7)	101/7 (94/6)	0.86	69/8 (90/10)	70/7 (91/9)	0.76
NAC** Yes/No (%)	109/48 (70/30)	67/41 (62/38)	0.21	51/26 (66/34)	50/27 (65/35)	0.87
LN Dissection 2-field /3-field (%)	76/81 (48/52)	87/21 (81/19)	<0.0001	56/21 (73/27)	56/21 (73/27)	1.00
Abdominal procedure Laparoscopy/ open	132/25 (84/16)	94/14 (87/13)	0.50	67/10 (87/13)	67/10 (87/13)	1.00

* SCC: squamous cell carcinoma

** NAC: neoadjuvant chemotherapy

Table 2 Operative outcomes of the patients treated with 2-D or 3-D laparoscopic system

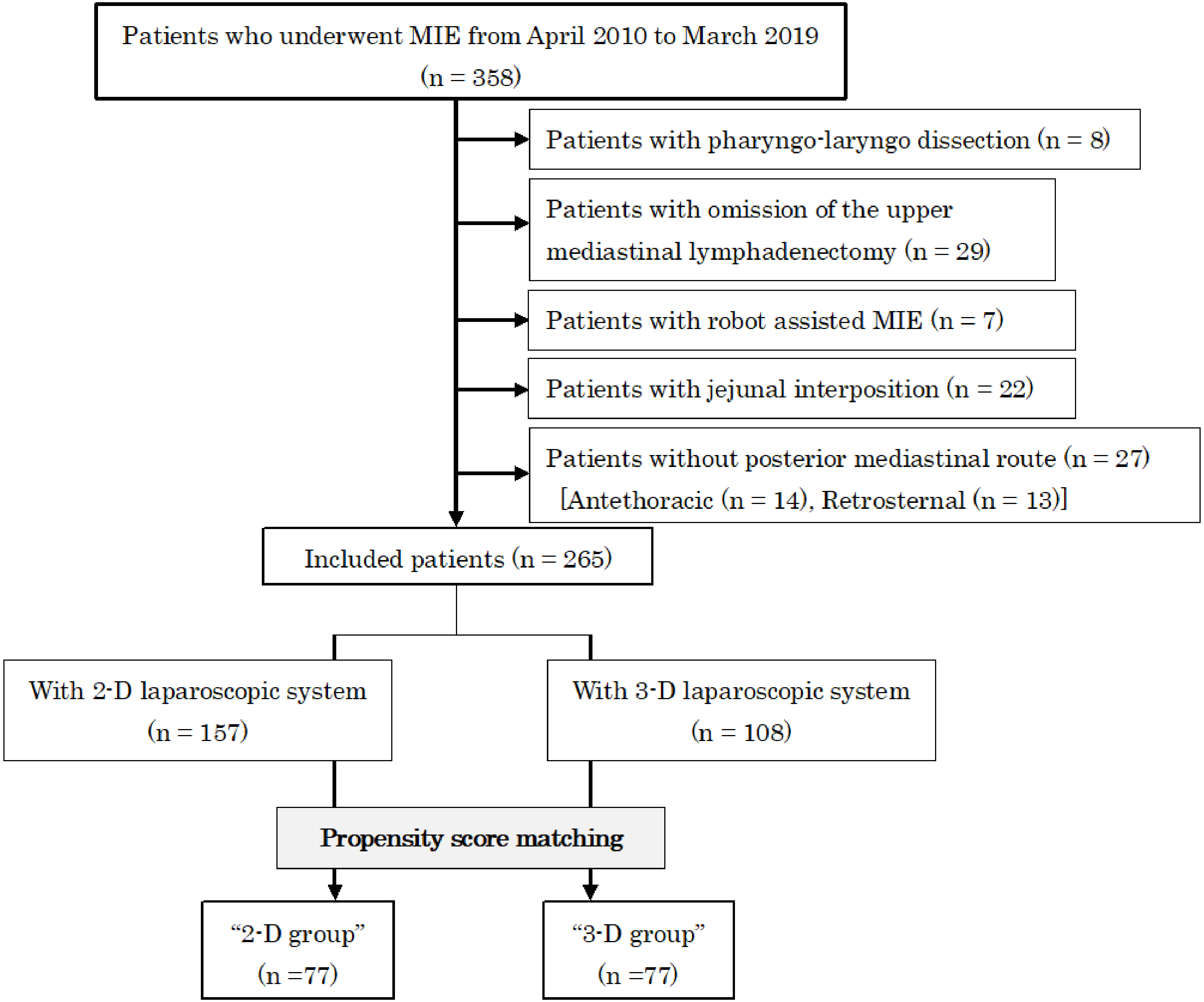
	Whole cohort (n = 255)			Matched cohort (n = 154)		
	2-D (n =157)	3-D (n =108)	*P*	2-D (n = 77)	3-D (n = 77)	*P*
Operation time, *min*						
Entire procedure*	683 [461-1061]	659 [354-872]	0.013	674 [491-871]	661 [354-872]	0.24
Thoracic procedure*	307 [159-582]	300 [172-570]	0.74	311 [159-523]	310 [172-540]	0.77
Number of retrieved mediastinal nodes, *n*	23 [3-74]	22.5 [1-56]	0.15	22 [7-74]	23 [2-56]	0.67
Number of harvested left RLN nodes, *n*	3 [0-25]	2 [0-11]	0.54	2 [0-25]	3 [0-11]	0.59
Blood loss, *mL* *	275 [0-1320]	127.5 [0-729]	<0.0001	260 [0-1160]	140 [0-698]	0.0003
Transfusion, yes (%)	38 (24)	18 (17)		20 (26)	13 (17)	0.18
Complication*						
Pneumonia, grade II ≦ (%)	37 (24)	13 (12)	0.018	18 (23)	10 (13)	0.09
IIIa ≦	14 (9)	4 (4)	0.09	8 (10)	3 (4)	0.11
Pneumonia(≧G2) with any RLN palsies (≧G1)	24 (15)	6 (6)	0.014	10 (13)	6 (8)	0.29
Pneumonia(≧G2) without RLN palsies (≧G1)	13 (8)	7 (6)	0.59	8 (10)	4 (5)	0.23
Left RLN palsy, grade I ≦ (%)	69 (44)	27 (25)	0.0014	32 (42)	22 (29)	0.09
II ≦	31 (20)	9 (8)	0.011	13 (17)	8 (10)	0.24
IIIa ≦	15 (10)	1 (0.9)	0.004	7 (9)	1 (1)	0.029
Right RLN palsy, grade I ≦ (%)	17 (11)	3 (3)	0.015	8 (10)	2 (3)	0.049
II ≦	10 (6)	1 (0.9)	0.029	4 (5)	1 (1)	0.17

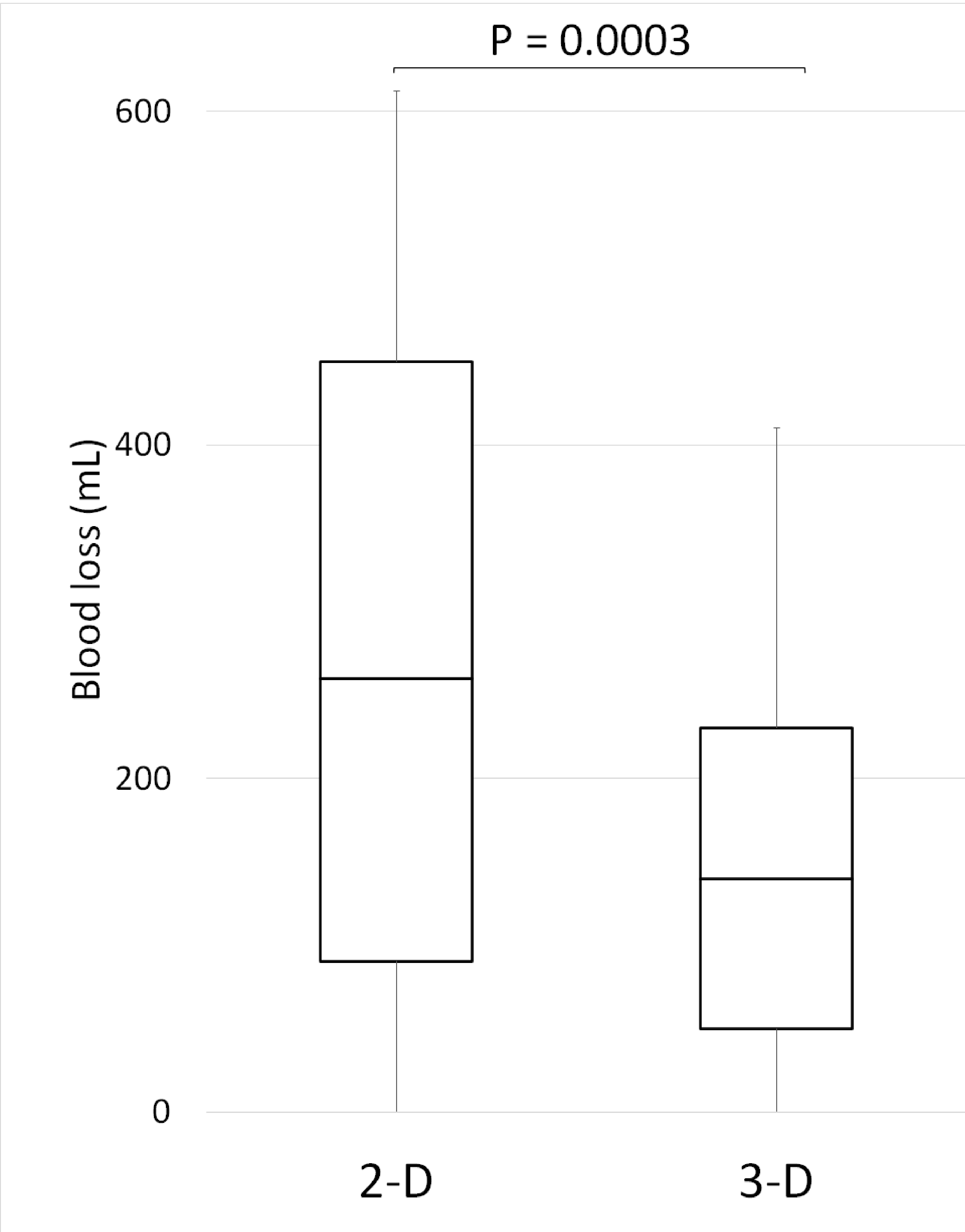
IIIa ≦	8 (5)	1 (0.9)	0.06	4 (5)	1 (1)	0.17
Leakage, grade II ≦ (%)	26 (17)	16 (15)	0.70	12 (16)	11 (14)	0.82
IIIa ≦	21 (13)	8 (7)	0.12	11 (14)	6 (8)	0.20
Postoperative mortality within 30 days after surgery (%)	2 (1.3)	1 (0.9)	0.75	1 (1.3)	1 (1.3)	1.00
Comprehensive Complication Index***	14.8 [12.6-16.9]	8.3 [5.6-10.9]	0.0002	14.3 [11.1-17.4]	8.5 [5.4-11.7]	0.011
Postoperative hospital stay, days*	31 [9-158]	25.5 [10-141]	0.0058	30 [17-150]	25 [10-141]	0.034

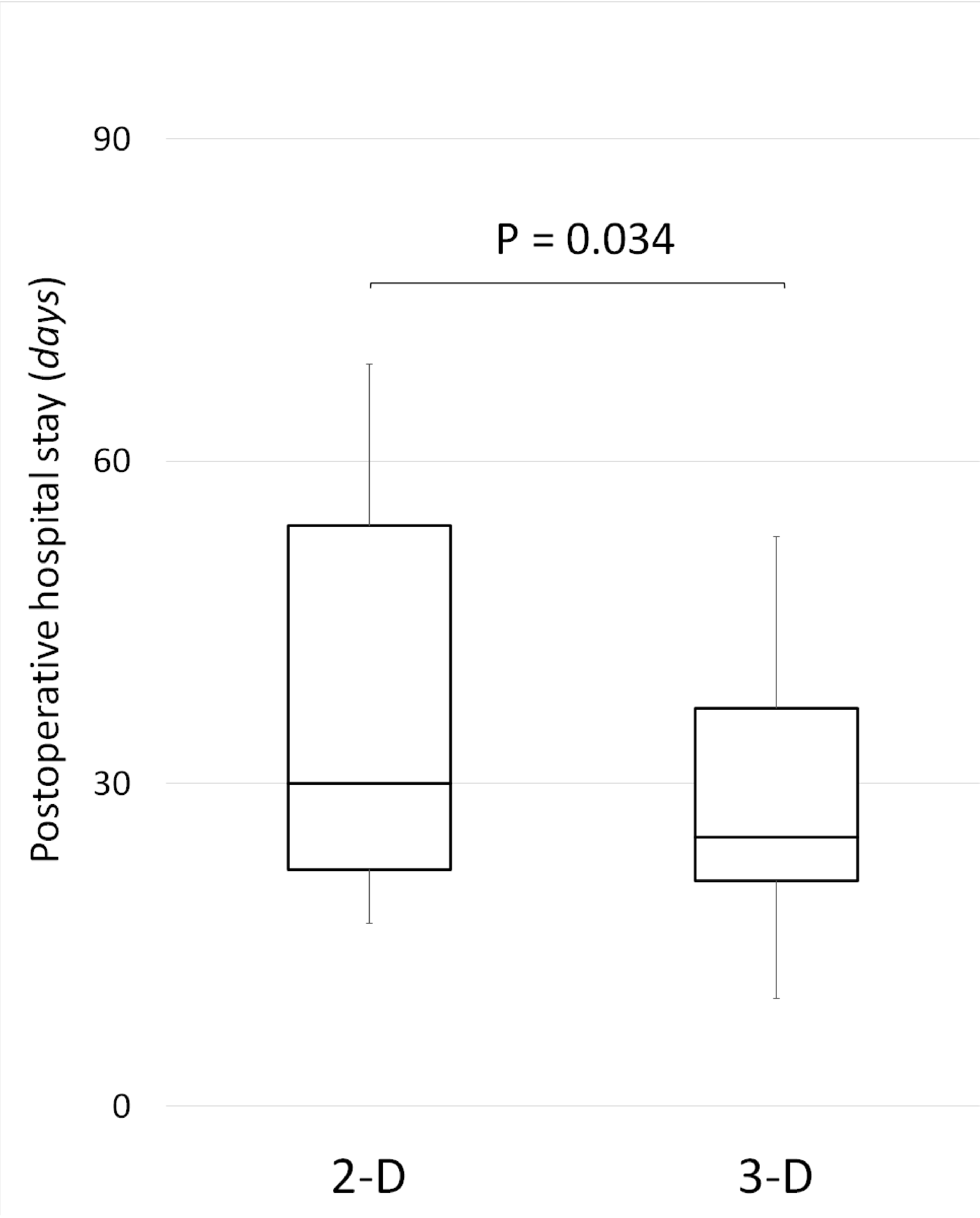
*median [min-max]

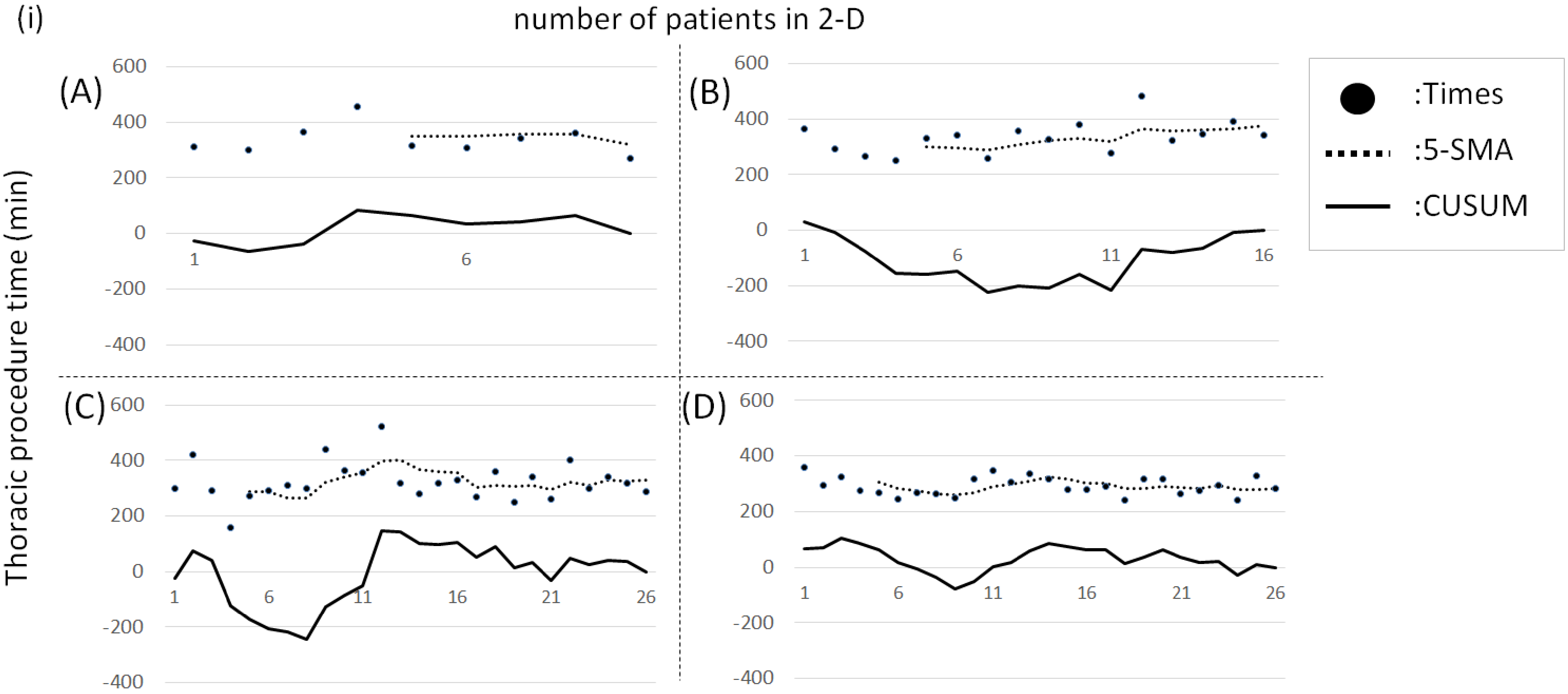
** Clavien-Dindo classification

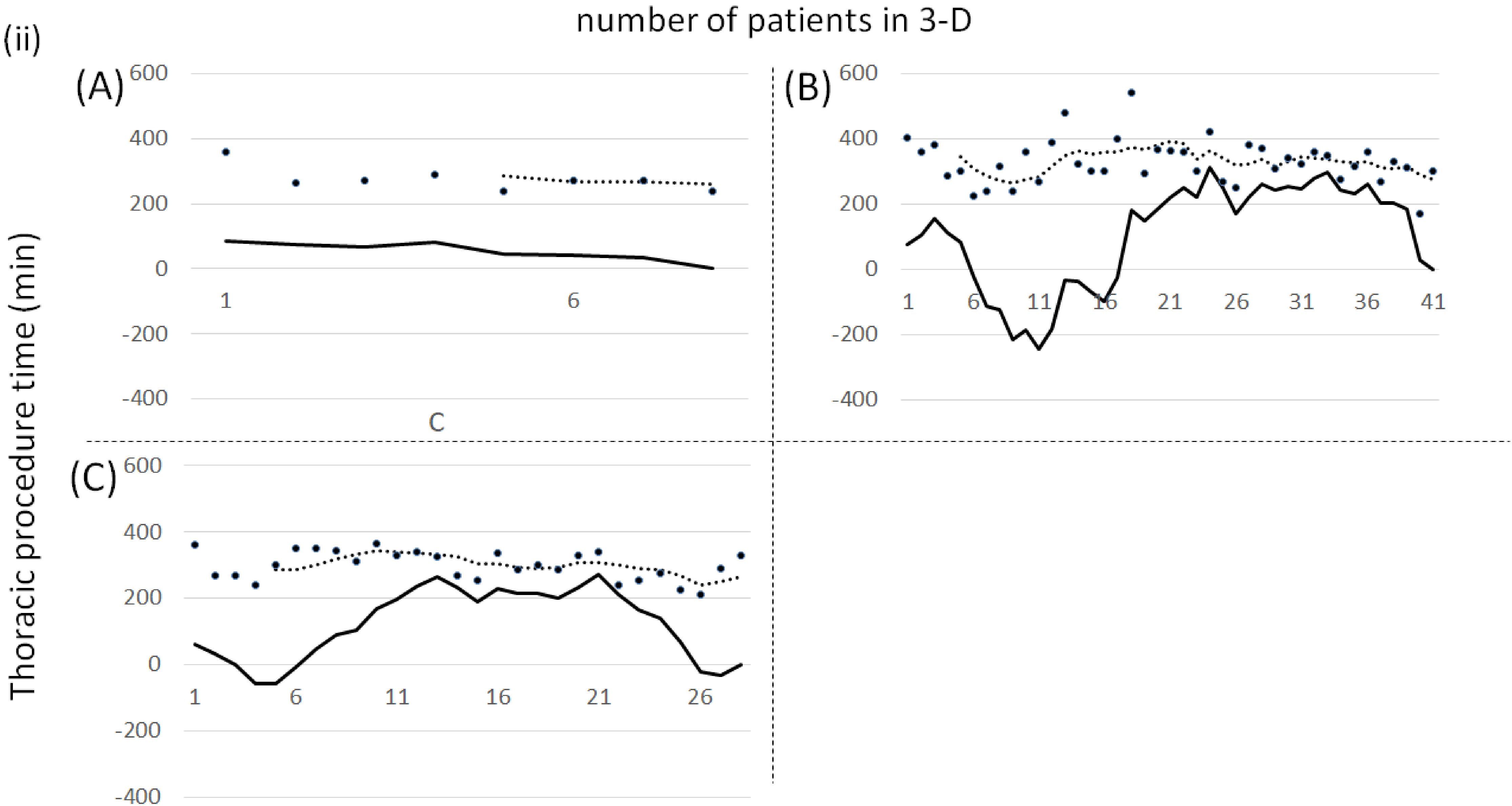
*** average [95% C.I.]


Patients who underwent MIE from April 2010 to March 2019
(n = 358)
Patients with pharyngo-laryngo dissection (n = 8)
Patients with omission of the upper mediastinal lymphadenectomy (n = 29)
Patients with robot assisted MIE (n = 7)
Patients with jejunal interposition (n = 22)
Patients without posterior mediastinal route (n = 27)
[Antethoracic (n = 14), Retrosternal (n = 13)]
Included patients (n = 265)
With 2-D laparoscopic system
(n = 157)
With 3-D laparoscopic system
(n = 108)
Propensity score matching
"2-D group"
(n =77)
"3-D group"
(n =77)


P = 0.0003
600
400
200
0
Blood loss (mL)
2-D
3-D


90
60
30
0
Postoperative hospital stay (days)
P = 0.034
2-D
3-D


(i)
number of patients in 2-D
Thoracic procedure time (min)
(A)
(B)
(C)
(D)
600
400
200
0
-200
-400
1
6
11
16
21
26
:Times
:5-SMA
:CUSUM



(ii)
number of patients in 3-D
Thoracic procedure time (min)
(A)
(B)
(C)
C
600
400
200
0
-200
-400
1
6
11
16
21
26
31
36
41