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Effect of Continuous Box-trainer Training on Laparoscopic Skills of Surgical Residents: A Prospective, Observational Study

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Abstract. *Background/Aim: As opportunities for hands-on surgical training during residency have decreased, off-the-job training before surgery is gaining importance. We developed a training program using a box-trainer for surgical residents. This study aimed to verify the effectiveness of the program. Using task-achievement time, we demonstrated the learning curve through continuous task training and verified the efficiency of our training tasks. In addition, we examined the circularity of the cut circle to evaluate the task accuracy and summarized the questionnaire results. Patients and Methods: A prospective, observational study was conducted at a single center with five trainees from April 2019 to March 2020. The training consisted of four tasks based on the Fundamentals of Laparoscopic Surgery module. The trainees had to achieve expert proficiency time targets. The task-achievement time and circularity of the cut circle were used for objective assessment; subjective evaluation was done using a questionnaire. Results: Although the learning curves of the task-achievement time seemed to reach a plateau between the third and the fifth skills lab, all the trainees achieved expert proficiency times for the three tasks. Circularity of the cut circle tended to be more accurate after training. All trainees perceived an improvement in their skills after the training program. The level of satisfaction of the training program was rated as 'very satisfied' or 'satisfied'. Conclusion: Continuous box-trainer training for 1 year may be effective for improvement in preoperative laparoscopic surgical skills of surgical residents.*

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Opportunities for hands-on surgical training during residency have decreased in recent times (1). However, because minimally invasive surgery has become a mainstream practice within general surgery, off-the-job training before performing surgery on patients is gaining importance (1). The performance of surgeons under the fundamentals of laparoscopic surgery (FLS) program, launched as a preoperative training module by the Society of Gastrointestinal and Endoscopic Surgeons, has been shown to correlate with intraoperative performance during laparoscopic surgery (2-4). This program incorporates training tasks using box-trainers to teach the surgical skills fundamental to laparoscopic surgery (2). The program sets a proficiency time with allowable errors as a task goal and also provides a recommended training schedule (5). Through this program, including goal-oriented training and scheduled practice, trainees can achieve proficiency standards, resulting in skill retention and decreased performance variation (6-9).

The FLS program involves five tasks, namely peg transfer (PT), precision cutting (PC), ligation loop, suture with extracorporeal knot, and suture with intracorporeal knot (IK) (2). These tasks were developed to train laparoscopic coordination skills, the use of certain laparoscopic instruments, and particular laparoscopic techniques (10). However, since the equipment and supplies used for the standard FLS training tasks are costly (11), repeated use and continuous training of these tasks are not feasible. Therefore, we developed alterative tasks similar to those in the FLS program. Among the standard FLS tasks, PT, PC, and suture with IK were incorporated into our tasks. Since the ligation loop required a special device and suture with an extracorporeal knot seemed to be less relevant for initial surgeries, these two were omitted in our tasks.

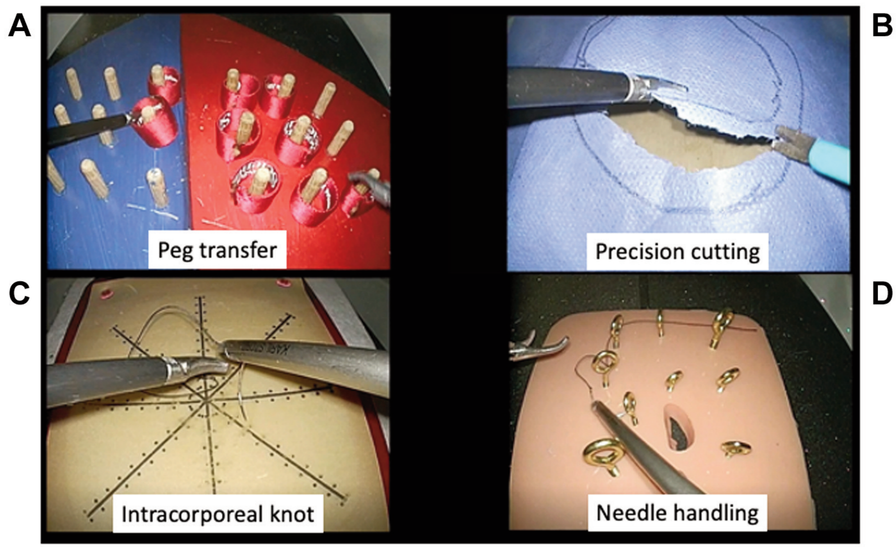

Figure 1. *The representative task views. (A) Peg transfer; (B) Precision cutting; (C) Intracorporeal knot; (D) Needle handling.*

Besides, a task for practicing needle handling (NH) was devised with reference to the task of robotic surgery (12). Our four tasks include the essential elements to acquire skills in laparoscopic coordination, laparoscopic instrument use, and particular laparoscopic techniques using low-cost and repeated-use task simulators.

There is still room for development on how to evaluate the effectiveness of surgical training. Moreover, the objective evaluation method, which has been used mainly in the FLS tasks and the previous reports, was task-achievement time (5, 6, 8, 9); our tasks were also evaluated using task-achievement time. To the best of our knowledge, there are no reports that examine the learning curve through continuous practice of the task and the efficiency of a training task, using the task-achievement time. Furthermore, as not only the speed but also the accuracy for task achievement is reported to be important, the evaluation method has been controversial (13). We devised the evaluation of the task accuracy using the circularity calculated in the PC task. We evaluated the effectiveness of our surgical training program using these objective evaluations and a questionnaire as a subjective evaluation for trainees.

We introduced and launched a training program in 2019 for preoperative training of surgical residents in our department. This study aimed to verify the effect of the program. First, using task-achievement time, we demonstrated the learning curve through continuous task training and verified the efficiency of our training tasks. Second, we examined the circularity to evaluate the task accuracy and summarized the questionnaire results.

Patients and Methods

Study design and participants. This prospective, observational, single-center study was conducted from April 2019 to March 2020. Surgical residents from the third to the sixth post-graduate year (PGY3 to PGY6) at our department and doctors planning to start surgical training in our department in 2019 were included in the study; those participants who attended the skills laboratory less than three times owing to a busy work schedule were excluded.

This study was approved by the institutional review board of Hokkaido University Hospital (Sapporo, Japan; No. 019-0212). All the participants were provided detailed information about the study, and written informed consent was obtained from each participant.

Tasks for laparoscopic skills training. The three tasks for this program were based on the FLS tasks (2): PT, PC, and suture with IK. The other one was based on the task of robotic surgery (12): NH. The four tasks are shown in Figure 1. In PT, all nine red-colored objects should be aligned on the nine pegs from the left side to the right side and then from the right side to the left side. After an object is moved, it should be handed over from the hand on the side at which the object is kept, to the other hand. The PT task is focused on laparoscopic coordination skills. For the PC task, a piece of cloth should be cut between a double circle line (3 mm width) using laparoscopic scissors. Trainees should cut the circle with appropriate counter traction such that the line is smooth and the circle is accurate. The PC task is focused on laparoscopic coordination skills and laparoscopic instrument use. For the IK task, trainees should perform one suture and three throws of a knot intracorporeally. The first throw must be a surgeon's knot or double throw, followed by two single throws. The IK task is focused on particular laparoscopic techniques. For the NH task, trainees should grasp and pass the needle through the ten rings in order. For the fifth ring, trainees should turn and hold the needle in the opposite direction while passing the needle through the ring. The NH task is

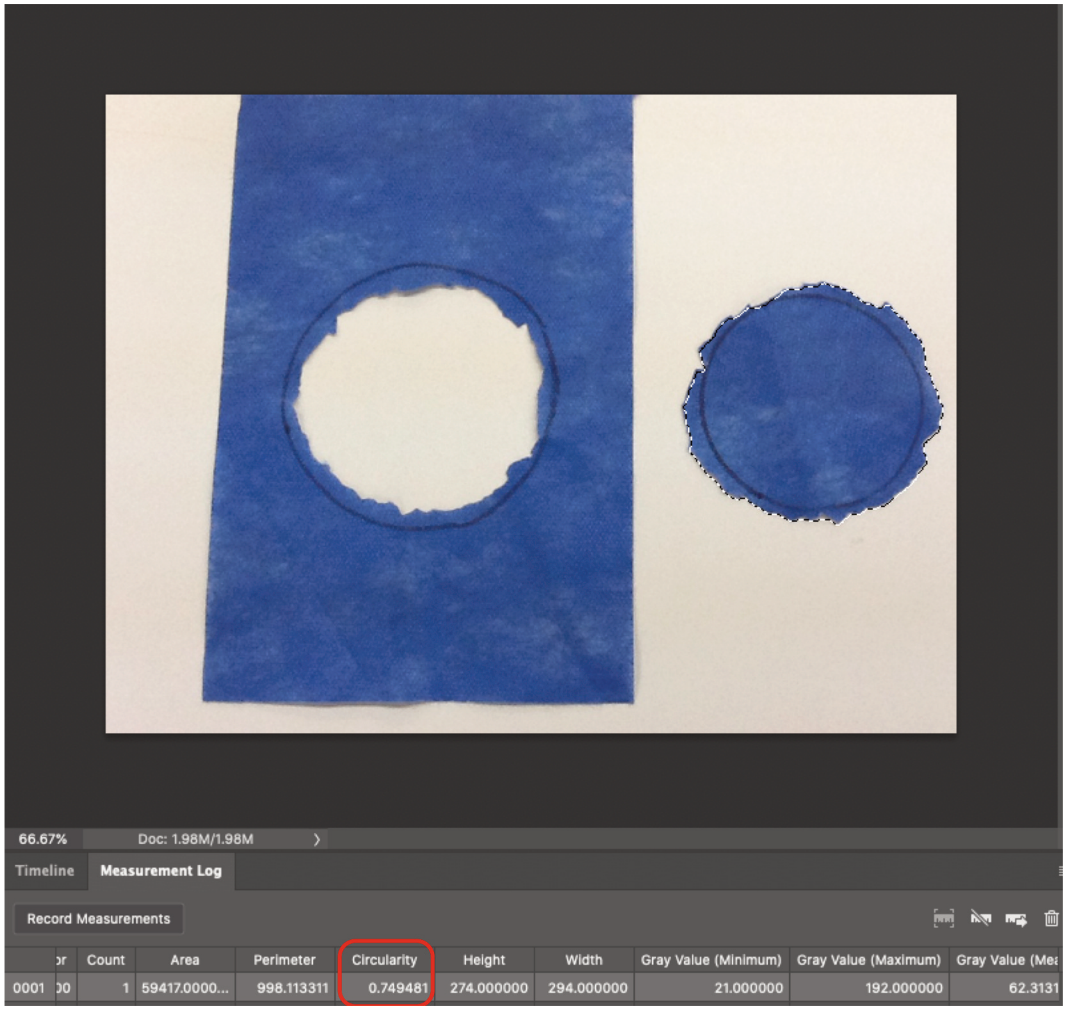

Figure 2. *A representative image for calculating the circularity of the cut circle on Photoshop™ . Red frame represents the circularity.*

focused on laparoscopic coordination skills and particular laparoscopic techniques. The task simulators were created by the authors themselves using materials purchased at a convenience store. All the trainees used a Hunter grasper and a needle driver to complete the PT, IK, and NH tasks and used a Hunter grasper in addition to laparoscopic scissors for the PC task. All the task videos are provided in the supplementary information. As the participants progressed through the program, task-achievement times were tracked for each resident annually.

Program schedule and assessment. The program was conducted for 1 year, from April 2019 to March 2020, and all the tasks were performed in a skills laboratory (lab) twice a month. The pre-training baseline performance was measured on all four tasks at the first skills lab. The participants were given the targets for meeting the expert proficiency times (EPT), which were determined using three expert surgeons' (KI, NI, and TY) mean task-achievement times. Expert surgeons were those who had passed the Endoscopic Surgical Skill Qualification System of the Japan Society for Endoscopic Surgery (14-16). Each skills lab consisted of 2 hours of practice followed by a measurement of the task-achievement time. However, not all the participants could attend all the skills labs owing to conflicting work schedules.

The objective evaluation was majorly based on the task-achievement time, while the accuracy of the PC task was evaluated by the circularity of the cut circle. A photograph of the cut circle was imported into Adobe Photoshop™ software for calculation of the circularity. A representative image for calculating the circularity of the cut circle is shown in Figure 2. The definition of circularity, corresponding to that of parameter *K* defined by Cox (17), is given as follows: $\text{Circularity}=4\pi\cdot(\text{Area}/\text{Perimeter}^2)$

These objective evaluations were carried out after each skill lab, and the feedbacks were provided to the participants.

Subjective evaluation was performed at the end of the program using a questionnaire, wherein the participants provided feedback on their perceived level of improvement in their skills through the program and whether they were satisfied with the training program. The questionnaire form consisted of the following two queries: 1)

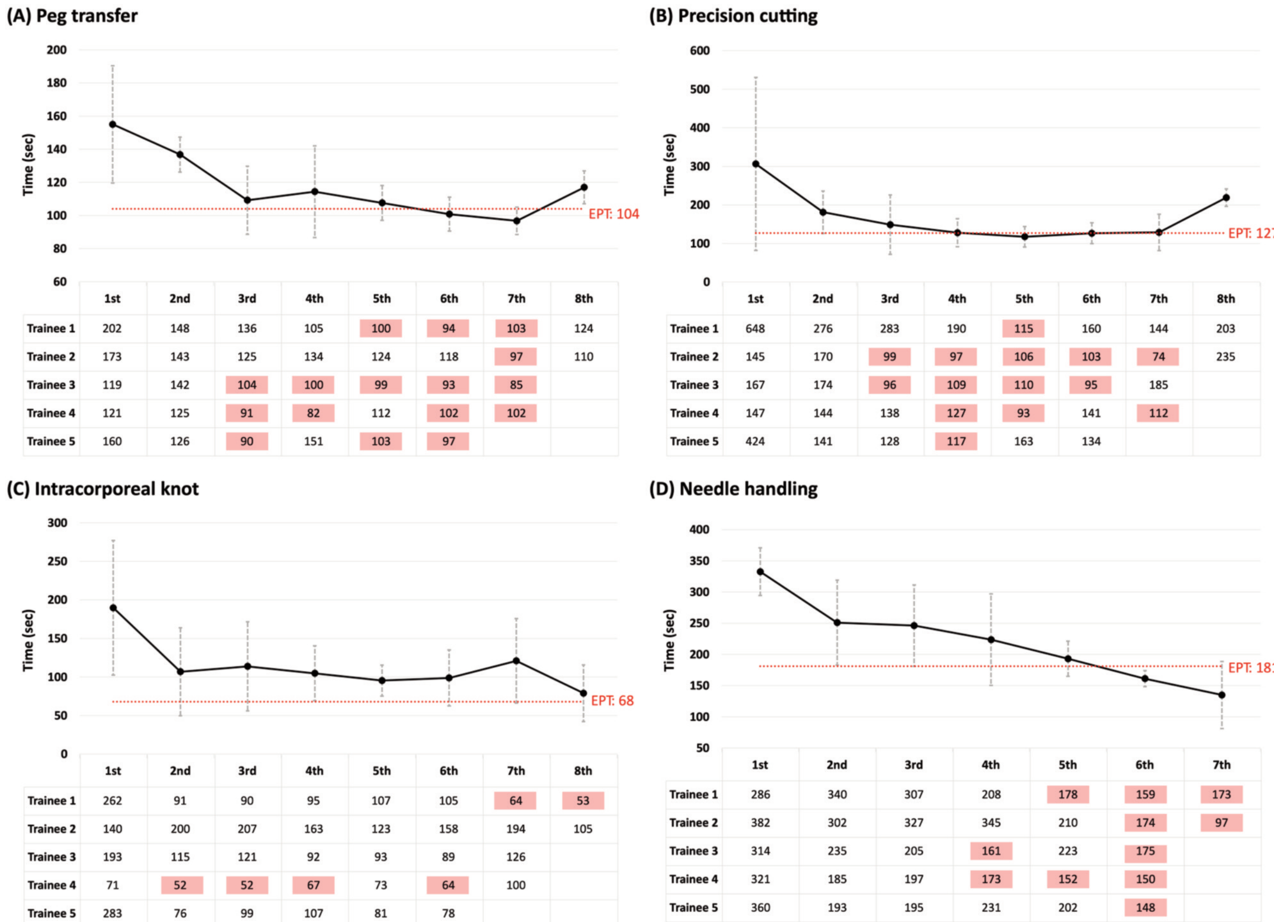

Figure 3. *The results of task-achievement time. The line graphs indicate mean values of task-achievement times. Error bars represent standard deviation. Red dotted lines show expert proficiency time (EPT). The tables below show the times for each trainee in each skills lab. The times that achieved EPT are highlighted in red. (A) Peg transfer; (B) Precision cutting; (C) Intracorporeal knot; (D) Needle handling.*

Table I. *Trainee characteristics.*

Characteristics	Trainee 1	Trainee 2	Trainee 3	Trainee 4	Trainee 5
PGY (years)	3	6	3	3	3
Surgical residency (years)	1	4	1	1	1
Dominant hand	Right	Right	Right	Right	Right
Experienced surgery (cases)	19	158	39	14	8
Experienced laparoscopic surgery (cases)	2	59	19	13	2

PGY: Post-graduate year.

’Do you feel that your skill improved after the training program? (How many folds was the post-training skill compared with the pre-training skill in self-assessment?)’; 2) ’Please choose your satisfaction with the program [very satisfied, satisfied, neutral, dissatisfied, very dissatisfied]’.

Statistical analyses. Continuous variables were assessed using the non-parametric Mann–Whitney *U*-test. Statistical analysis was performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan, version 1.50), which is a modified version of R Commander (version 2.6-0) that was designed to add

Table II. *Results of Ihe subjective evaluation using a questionnaire.*

Questions	Trainee 1	Trainee 2	Trainee 3	Trainee 4	Trainee 5
Skill improvement	5-fold	1.5-fold	3-fold	1.5-fold	20-fold
Satisfaction	Satisfied	Satisfied	Very satisfied	Very satisfied	Very satisfied

statistical functions that are frequently used in biostatistics (18) and is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria, version 3.6.1).

Results

Trainee characteristics. Six trainees participated in this training program in 2019. One trainee was excluded from the study because he attended the skills lab only twice. Finally, five trainees were included in the study. The trainee characteristics are shown in Table I. The trainee group consisted of four trainees who were in PGY3 and one who was in PGY6 with a 4-year surgical residency training. The number of laparoscopic surgeries performed until the training program ranged from 2-59 cases.

Task-achievement time and accuracy for precision cutting task. The calculated EPTs were 104 s for PT, 127 s for PC, 68 s for IK, and 181 s for NH. The learning curves of the task-achievement time seemed to reach a plateau in all the tasks between the third and the fifth skills lab. All the trainees achieved EPTs at least once for PT, PC, and NH; however, only two trainees achieved EPT in IK, as this task was more complex than the other three tasks. The results are shown in Figure 3.

The median value of the pre-training (at the first skills lab) circularity of the cut circle of all the trainees was 0.743 (range=0.643-0.785), whereas that of the post-training (at the last skills lab for each trainee) value of all the trainees was 0.791 (0.756-0.796), as seen in Figure 4. The post-training circularity of the cut circle was more accurate than the pre-training circularity (p=0.095).

Self-assessment on skill improvement and satisfaction regarding the program. All the trainees perceived an improvement in their skills after the training program. Trainee 1 perceived a five-fold improvement; trainees 2 and 4 perceived a one and a half-fold improvement, and trainees 3 and 5 perceived a three-fold and twenty-fold improvement, respectively. Three trainees were 'very satisfied', and two were 'satisfied' with the training program when asked about their level of satisfaction after the program. The results are summarized in Table II.

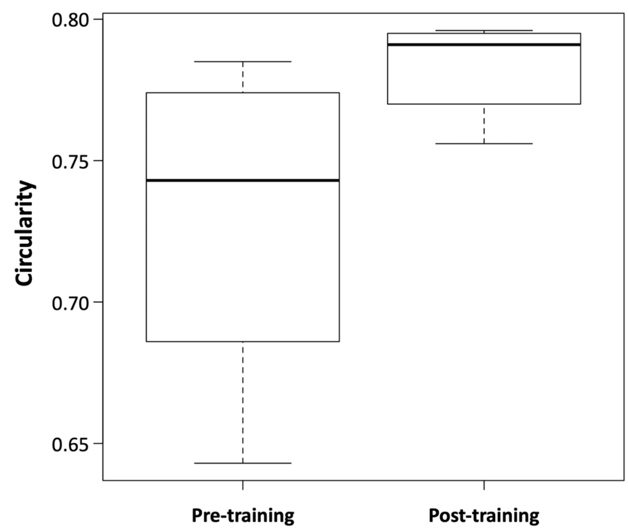

Figure 4. *The comparison of the circularity of the cut circle between the pre- and post-training.*

Discussion

As laparoscopic and robotic surgeries become more mainstream, preoperative training becomes more important (1). FLS tasks, which are relatively simple, are used in several situations (3, 4, 6, 19), including teaching the skills required for laparoscopic surgery. We developed a training program using original tasks based on the FLS tasks (2) as a laparoscopic surgical training for surgical residents. In this study, to verify the effectiveness of the program, the results indicated that continuous box-trainer training for 1 year could increase the speed and accuracy of laparoscopic surgical skills. We consider that the learning curve demonstrates the efficiency of our training task because the residents have reached the expert level. Subjective evaluation indicated that the satisfaction of the residents participating in this program was high.

Despite reports on the usefulness of training using cadavers and animals (20-22), both have the implication of surgical simulation rather than the training of basic movements such as coordination skills. When using cadavers and animals for training, it is not feasible for surgeons to repeatedly practice the basic skills (23, 24). Thus, box-trainer training is important for the acquisition of basic surgical skills. The equipment and supplies used for the standard FLS training tasks were reported to be expensive (11). Placek *et al*. reported that proficiency training using an inexpensive and ergonomically different platform showed no difference in outcome when compared with that using the standard FLS platform (25). Therefore, training in our box-trainer using a low-cost task simulator, which can be used repeatedly, would be effective for surgical training. We believe that our tasks and training program can be easily introduced at any institute.

Although the evaluation method differed among reports (13), we used task-achievement time and circularity for objective evaluation. A previous study suggested that setting attainable goals can improve trainee performance more than setting no goals or unattainable goals (26). In this study, we determined the EPTs using three expert surgeons' mean task-achievement times. As all the trainees achieved the EPTs for three tasks, we considered our EPTs attainable. The circularity of the cut circle was used to assess the accuracy of the technique, and our results showed a marked improvement in the trainees' skills post-training. In the literature, there have been no reports of using the circularity of the cut circle for objective assessment. Furthermore, we used self-assessment questionnaires for the subjective evaluation. In the future, the usefulness of these evaluation methods and the influence of the training program on the clinical performance of surgeons should be examined.

In the IK task, only two trainees achieved EPT. Because suturing skill is one of the most challenging skills to acquire and gain proficiency in, the various methods of instruction have been reviewed by a previous report (27). Our teaching methods were live demonstrations by expert surgeons at the beginning of the first skills lab and feedback after each skills lab. However, our results showed that the achievement of EPT in IK was less than that in the other tasks. An optimal teaching method should also be an issue for future studies.

Our study had some limitations. First, this was a single-institution study. Second, the sample size was too small to verify the training effect; a study with a larger sample size will be required in the future. Third, the number of training sessions that each trainee could participate in was different owing to conflicting work schedules. Fourth, the questionnaires used in the subjective evaluation of this study were created in our department and have not yet been validated.

In conclusion, our study demonstrated that continuous box-trainer training may improve the speed and accuracy of laparoscopic surgical skills of surgical residents. We believe that these results will contribute to setting attainable goals, and continuous training will improve surgical resident performance on basic skills. We will continue to verify the effectiveness and usefulness of this training program.

Supplementary Material

Available at: https://vimeo.com/774799143

Conflicts of Interest

The Authors have declared that there are no competing interests in relation to this study.

Authors' Contributions

KI, NI, SH, HM, YM, TY, and AT conceptualized and designed the study. KI and NI wrote the manuscript. KI performed the statistical analyses. KI, KY, TI, RT, TF, TH, and KH contributed to the development of the training program. KI, NI, SH, KY, TI, RT, TF, TH, KH, HM, YM, and TY interpreted the results. AT supervised the study. All Authors have read and approved the final manuscript.

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