Novel Surgical Skill Evaluation with Reference to Two-handed Coordination

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Original Article

Novel Surgical Skill Evaluation with Reference to Two-handed Coordination

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Abstract

Introduction : We evaluated the differences in instrument manipulation skills between expert laparoscopic surgeons and novices.

Methods : Six expert surgeons who had performed more than 500 laparoscopic surgeries and one skilled instructor at Kyushu University Training Center for Minimally Invasive Surgery, and 20 medical students who had experienced no laparoscopic surgery were enrolled. A new skill assessment task was designed using zippers on an unstable, mobile platform in a box trainer. The examinees were asked to close the zippers, while trying to avoid moving the platform. The path lengths of the tips of the instruments and of the platform were measured, and the performance time was also recorded. Surgical skill score was calculated from the correlation between the path lengths of the instruments and that of the platform, in addition to the performance time.

Results : The path lengths of the tips of both instruments and of the platform were significantly shorter in the experts than in the novices (all $p < 0.05$). The performance time was also significantly shorter for experts than novices ($p < 0.05$). The surgical skill score was significantly higher for experts than novices ($p < 0.01$).

Conclusion : The differences in the instrument manipulation skills between expert laparoscopic surgeons and novices could therefore be evaluated using our surgical skill scoring system.

Key words : Clinical skills, Laparoscopic surgery, Two-handed coordination skills

Introduction

Laparoscopic surgery has many advantages over open surgery, including less postoperative scarring, a shorter recovery period and better cosmetic outcomes[1)]. However, surgeons need to acquire specific laparoscopic surgery skills to safely and accurately perform these procedures. These skills include eye-hand coordination, depth perception and the translation of two-dimensional (2D) video images into a three-dimensional (3D) working field.

The identification and assessment of specific components of these skills would be useful for effectively teaching laparoscopic surgery skills. These skills include hand-eye coordination, depth perception, translation of 2D video images into a 3D working field and the ability to maneuver

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instruments well with both hands. Identification of specific components of these skills can help to assess the specific skills of expert surgeons, and can help with the effective teaching of laparoscopic surgery skills. In this study, we focused on the ability to maneuver instruments well with both hands, using a newly designed assessment and training task.

Various training simulators for laparoscopic surgery skills have been developed[2)3)]. Surgical skills are typically evaluated by measuring the path lengths of the tips of surgical instruments using magnetic tracking sensors[4)~6)], and experienced surgeons are generally able to perform tasks with shorter path lengths than inexperienced operators[3)~5)]. Although previous studies have included the assessment of two-handed skills among several other assessed skills, no previously described methods of assessing laparoscopic surgery skills were designed to specifically assess the ability to maneuver instruments well with both hands, which is not discussed as often as other components of surgical skill[3)~7)]. Therefore, we aimed to develop a method for specifically evaluating the ability to maneuver instruments well with both hands during laparoscopic surgery. Our novel method was designed for both the assessment and training of two-handed coordination skills.

Materials and Methods

Subjects

Six expert surgeons who had each performed more than 500 laparoscopic surgical procedures and one skilled instructor at Kyushu University Training Center for Minimally Invasive Surgery (expert group) and 20 medical students who had not performed any laparoscopic surgery (novice group) were enrolled in this study. Each group included one left-handed person. Participants were given informed consent by staff of the Kyushu University Training Center for Minimally Invasive Surgery and voluntarily agreed to participate.

Skills Assessment Task

We designed a new task for evaluating laparoscopic surgery skills (Fig. 1). A module consisting of five zippers attached to an unstable, mobile platform made from a plastic plate, such as a CD case, was placed inside a laparoscopic box trainer, so that it could slide easily within the box trainer while an examinee was preforming an assessment task. A six degrees-of-freedom (DOF) magnetic tracking sensor was mounted to the center of the platform (Fig. 1a, 1b), below the working space for the task. Each zipper was oriented in a different direction on the platform and was fixed to the mobile platform. The task module measured 60 mm × 60 mm × 15 mm (Fig. 1a), which is suitable for use in ordinary training boxes (e.g. Karl Storz)[7)]. The examinees were asked to close the zippers using dissection forceps in both hands, while trying to avoid sliding the platform within the box. A six DOF magnetic tracking sensor was mounted on the tip of each dissecting forceps (Fig. 1c, 1d).

Examinees were asked to perform two tasks. First, they were asked to trace the pattern of the zippers in the air above the zippers, without touching the zippers to provide control trajectory data, in the specified order (Nos. 1 to 5, Fig. 1b) (task 1). Second, they were asked to close the open zippers in the specified order (task 2), while trying to avoid movement of the platform within the box.

Data Collection

The data collected included the performance time, the path lengths of the tips of the instruments in tasks 1 and 2, the path lengths of the platform in tasks 1 and 2 and the correlation between the path lengths of the platform and the instruments.

The distances between the tracker and the sensors were measured using the magnetic tracking system[8)9)], and the data were used to calculate the path lengths. We defined the ideal path length of each examinee as the path length of task 1, and the actual path length of each

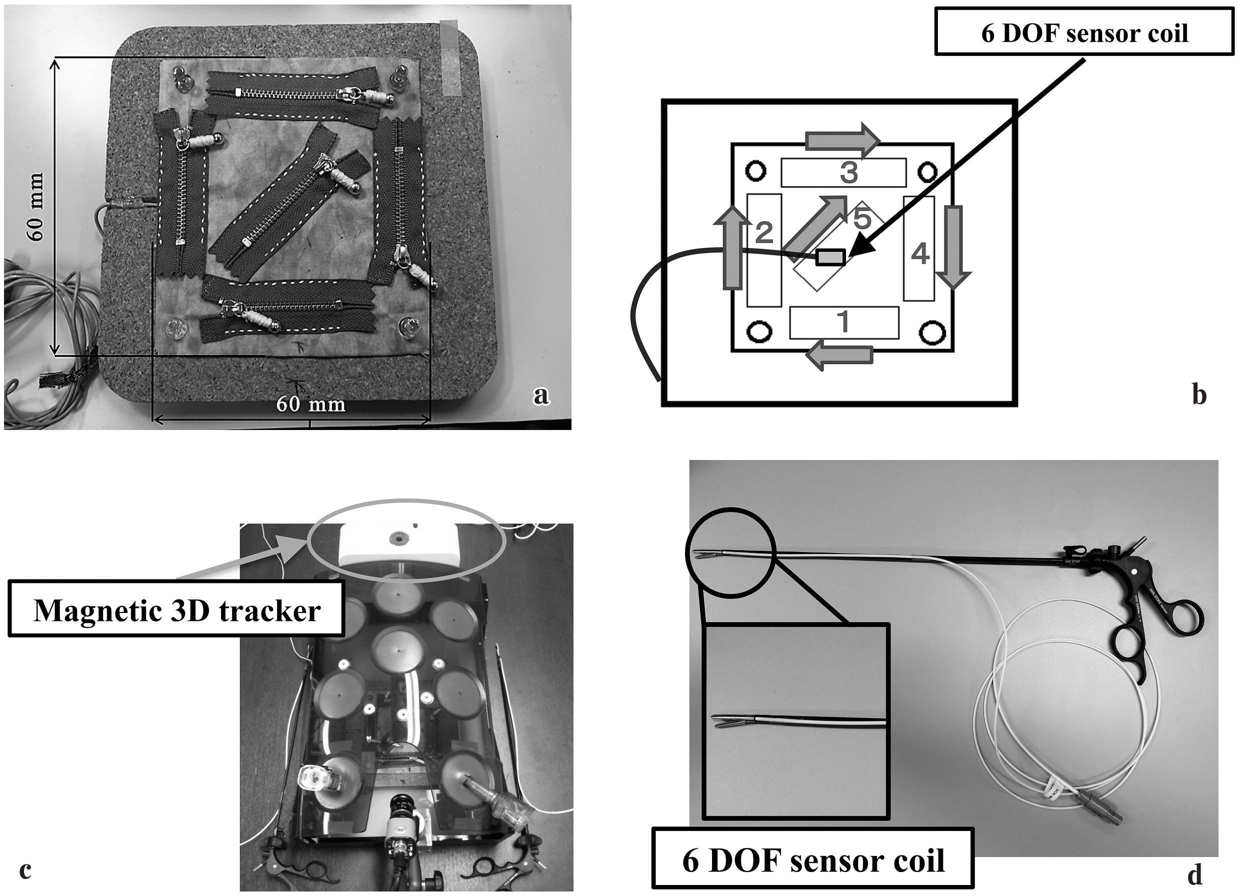

Fig. 1 A new laparoscopic surgical skills assessment system for two-handed coordination using a magnetic tracking system (*DOF*, degrees of freedom)
a. A module consisting of five zippers was attached to an unstable, mobile platform made from a plastic plate, such as a CD case, so that it could slide easily within the box trainer while an examinee was preforming an assessment task. The task module measured 60 mm × 60 mm × 15 mm, which is suitable for use in ordinary training boxes.
b. A six degrees-of-freedom (DOF) magnetic tracking sensor was mounted to the center of the platform, below the working space for the task. Each zipper was oriented in a different direction on the platform and fixed to the mobile platform.
c. An overview of the task. A magnetic 3D tracking system was set on the top side of the training box.
d. A six DOF magnetic tracking sensor was mounted on the tip of each dissecting forceps.

examinee as the path length of task 2. We defined the path length of this task as the value resulting from the subtraction of the path length in task 1 from the path length in task 2. The path length of the platform (d_S) and the path length of the instruments (d_I) were both calculated. The correlation between d_S and d_I was then compared between the expert and novice groups. The subjects were not informed of the types of data being collected.

Statistical Analysis

The measurements were compared between the expert and novice groups using Student's *t*-test, and the correlations between d_S and d_I were compared using a simple linear regression analysis. The correlation coefficient (R^2 value) between d_S and d_I was compared between the two groups. The analyses were performed using the R statistical software program (R Development Core Team, 2014). Statistical significance was set at $p < 0.05$.

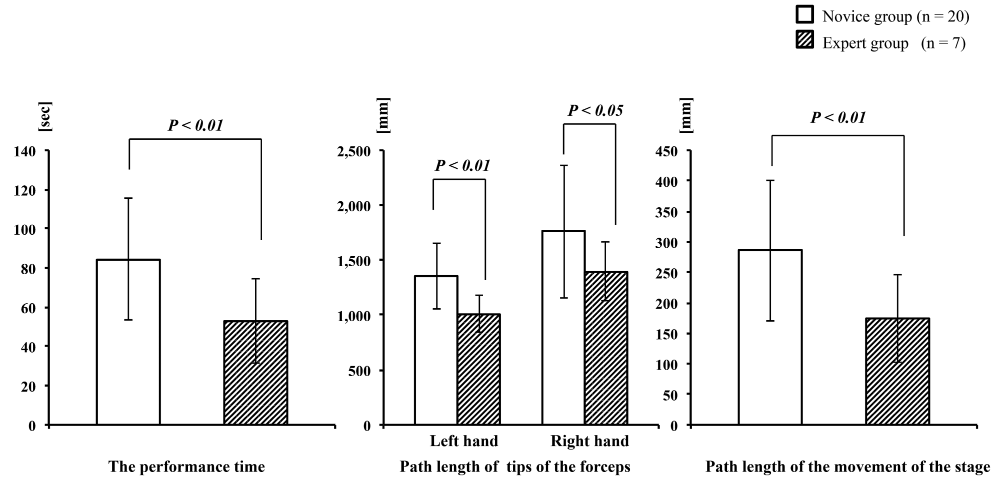

Fig. 2 The data collected during the evaluation task. The values are expressed as the means ± SD (*Plain bar*, novice group ; *shaded bar,* expert group)

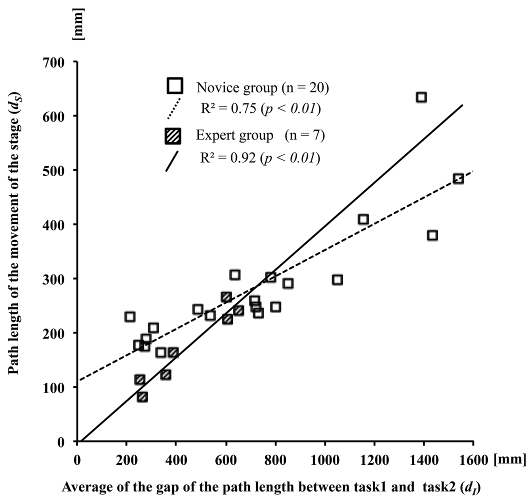

Fig. 3 The correlations between the path length of the platform (d_S) and the path length of the instruments (d_I) in the expert and novice groups. The path lengths were calculated by subtracting the absolute path length in task 1 from the absolute path length in task 2. The correlations were compared between the expert and novice groups. The correlations are expressed as the R^2 values. (*Plain marker, solid line* novice group ; *shaded marker, dashed line* expert group)

Results

Fig. 2 shows the performance time, path length of the tips of the instruments, and path length of the platform in the expert and novice groups. The mean performance time was significantly shorter in the expert group than in the novice group (52.8 ± 21.3 s vs. 84.5 ± 31.3 s ; $p < 0.01$). The path length of the tips of the instruments was significantly shorter in the expert group than in the novice group for both the right hand (1397.4 ± 267.5 mm vs. 1759.2 ± 604.3 mm ; $p < 0.05$) and the left hand (1008.5 ± 169.1 mm vs. 1355.3 ± 300.9 mm ; $p < 0.01$). The path length of the platform was significantly shorter in the expert group than in the novice group (173.8 ± 71.4. mm vs. 285.7 ± 115.4 mm ; $p < 0.01$).

Fig. 3 shows the correlations between the d_S and d_I in the expert group ($R^2 = 0.92$, $p < 0.01$) and the novice group ($R^2 = 0.75$, $p < 0.01$).

Assessment of the Tasks and Analysis of the Ability to Maneuver Instruments with Both Hands

The correlation between the d_S and d_I was significantly higher in the expert group than in the novice group. As the number of procedures a surgeon has performed is regarded to be one of the best indicators of surgical skill[10)~12)], surgeons who have performed many procedures are generally considered to be experts[13)]. As all of the surgeons in this study were considered to be experts, we considered that other surgeons would approach this expert correlation as they gained experience. A surgical skill score to assess the ability to maneuver instruments well with both hands was therefore developed using the correla-

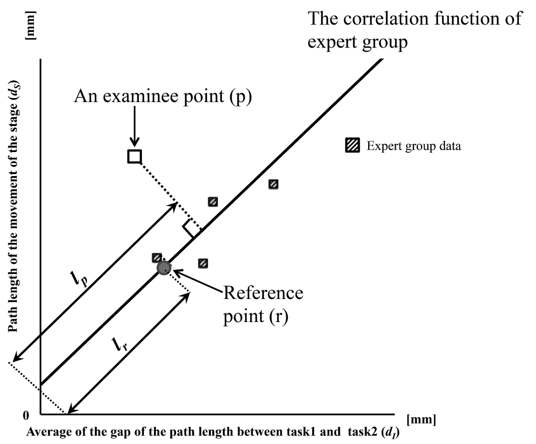

Fig. 4 An illustration of values used to calculate the skill score using the correlation function of the expert group.

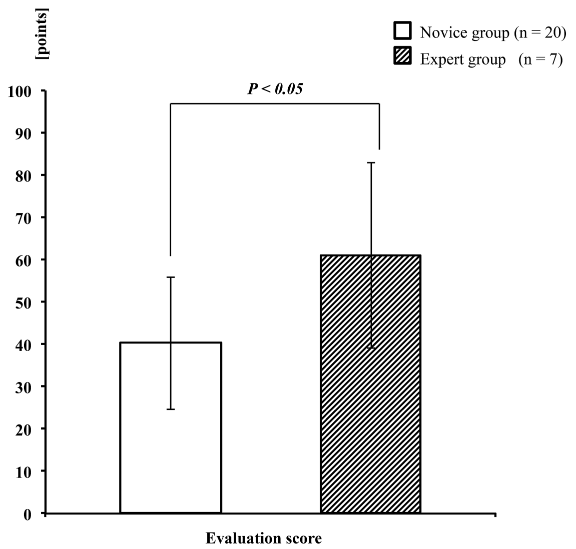

Fig. 5 The scores for two-handed coordination skills, calculated using the correlation function of the expert group. The values are expressed as the means ± SD (*Plain bar*, novice group ; *shaded bar*, expert group)

tion between the d_S and d_I in the expert group. The surgical skill score, S, consisted of two evaluations : 1) the movement of the forceps and the task plate and 2) how quickly the surgeons completed the task. A perfect score was 100. S was calculated as follows :

$$S=S_I+S_T \qquad (S\leq 100)$$

$$S_I=50\,\frac{l_R}{l_P} \qquad (S_F\leq 50)$$

$$S_T=50\,\frac{T_E}{T_A} \qquad (S_T\leq 50)$$

S_I was a skill score for maneuvering the instruments, including the forceps and the mobile platform, calculated using l_R (the distance from the intersection of the correlation function line and a perpendicular line from the shortest path length of the tips of the instruments in the expert group, to the intersection with the y-axis) and l_P (the distance from the intersection of the correlation function line and a perpendicular line, to the intersection with the y-axis) (Fig. 4). S_T was a skill score for performance time to complete the task, calculated using T_E (the fastest time in the expert group) and T_P (the performance time of the examinee).

The correlation function for the expert group was used to determine the regression line for calculating S_I (slope, 0.40 ; intercept, −0.60 ; coefficient of determination, 0.92 ; Fig. 3).

As expected, the surgical skill score, S, for assessing the operator's ability to maneuver instruments well with both hands was significantly higher in the expert group than in the novice group (61.1 ± 21.9 vs. 40.3 ± 15.7 ; $p < 0.05$; Fig. 5).

Discussion

Surgeons need to acquire specific skills to safely and accurately perform laparoscopic surgery procedures. These skills include hand-eye coordination, depth perception, translation of 2D video images into a 3D working field and the ability to maneuver instruments well with both hands. The identification of specific components of these skills can help to assess the specific skills of expert surgeons, and help with the effective teaching of laparoscopic surgery skills. In this study, we focused on the ability to maneuver instruments well with both hands, using a newly designed assessment and training task.

When eating, we coordinate hand movements to accomplish tasks such as using a knife and fork or chopsticks and a rice bowl, and each hand usually has a different role. We usually do not consciously recognize the specific components of our hand movements while we are eating, because both hands are proficient in their roles. A similar situation applies to performing laparoscopic surgery. For example, the dissection of a vessel involves picking up and holding the tissue with one hand and cutting the vessel using an electric scalpel with the other hand. Although the surgeon can grasp a vessel or operate an electric scalpel with one hand, successful achievement of this task involves the ability to maneuver instruments well with both hands. The surgeon can apply suitable tension to the vessel with one hand to avoid tissue injury, and can adjust the angle of the scalpel with the other hand. Galna and Sparrow reported that good bimanual motor coordination allows participants to perform the same workload with a reduced metabolic cost[14]. Hofstad et al. also mentioned that bimanual dexterity measures the ability to control both instruments simultaneously, which requires a high level of control of the nondominant as well as the dominant hand[15]. Spaun et al. reported that bimanual coordination tasks have the shortest performance times, and are easier to learn using an open surgery paradigm in endoscopic surgery[16]. Our results support the above reports and suggest that one of the most important skills for performing laparoscopic surgery is the ability to maneuver laparoscopic instruments well with both hands.

The present task was designed such that the difficulty of closing a zipper using only one hand, and the ability to maneuver instruments well with both hands, played an important role in closing the zippers on the mobile platform. We consider this task to be suitable for assessing the ability to maneuver laparoscopic instruments well with both hands, because the correlation between the path lengths of the platform and the instruments was much higher in the expert group than in the novice group. The correlation between the path lengths of the instruments and the platform was shown by a regression line in the expert group, which might indicate that surgeons become more proficient with regard to the ability to maneuver instruments well with both hands as their experience increases. We used these findings to develop a score to assess the ability to maneuver instruments well with both hands, which we refer to as "two-handed coordination skills".

The number of procedures a surgeon has performed is generally considered to be one of the best indications of surgical skill, and surgeons who have performed many procedures are considered to be experts. Experiences enable surgeons to find strategic solutions when faced with difficult surgical situations, and are able to manage difficult procedures using their advanced technical skills. This report presents a newly designed task and describes a new scoring system for the assessment of two-handed coordination skills[17]. Most previous studies of laparoscopic surgery skills compared expert surgeons who had performed many procedures with novices who were medical students or residents[5)18], and found that the expert group performed better than the novice group in skills evaluation tasks. Some of the most commonly measured parameters using virtual reality simulators are the performance time, path lengths of the tips of the instruments, errors and performance scores[19)~22]. In our study, the performance time and the path lengths of the tips of the instruments were used to evaluate the suitability of the task to assess the laparoscopic surgical skills, and these parameters were also found to be useful, as in the previously reported studies[19)20)23].

Yamaguchi et al[3]. reported on skills training for laparoscopic surgery, and suggested that improvement of the technique of the non-dominant hand was particularly important. They found that the novice group improved the skills of their non-dominant hand more than the expert group. Our newly developed task can train both hands, and may be useful for improving surgical skills.

In conventional open surgery, the surgeon can directly palpate and manipulate the tissues with his or her hands, can observe the internal organs of the patient, his own hands and the instruments, can manipulate the tissues in the surgical field using his hands and the surgical instruments and can obtain direct feedback. During laparoscopic surgery, the surgeon's vision is limited by the laparoscope and by manipulation of the tissues with the instruments. Ohuchida et al[24]. and Uemura et al[25]. reported differences in the hand motions of laparoscopic surgeons using 2D and 3D displays. Subjects who used 3D displays had significantly better movements of both hands, and better depth perception, than those who used 2D displays. Training for two-handed coordination skills could reduce the effects of a lack of depth perception during laparoscopic surgery.

During dissection, surgeons use both hands to manage the positions of the organs ; during suturing, both hands are needed to manage the positions of the needle and suture material. Two-handed coordination is therefore considered to be an important basic skill for laparoscopic surgeons.

Improvement of laparoscopic surgery skills can be aimed at specific core skills, such as psychomotor skills, hand-eye coordination or the translation of 2D images into 3D perception[20)26)27)]. Careful evaluation of the highly complex skills required for laparoscopic surgery can help surgeons to improve their skills[28)~31)]. Our study describes a score for the assessment and training in two-handed coordination skills. We would eventually like to establish similar systems for the assessment of other skills essential for laparoscopic surgery, and to integrate these scores to assess overall laparoscopic surgery skills to provide an objective assessment of the suture ligature method for the laparoscopic intestinal anastomosis model, as in a previous report[32)].

To make it more convenient for laparoscopic surgeons to use this system, it will be necessary to omit the magnetic tracking system. This is because the tracking system is too expensive for daily use and too bulky, with a heavy magnetic generator and plugged cables, making it less like an actual surgery. A possible answer is to use an image processing system to track the forceps in both hands instead of using the magnetic tracking sensors. In conclusion, the differences in the instrument manipulation skills between expert laparoscopic surgeons and novices could be accurately evaluated using our surgical skill scoring system, and this scoring system might therefore become useful for laparoscopic surgery training in the near future.

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Disclosures

Munenori Uemura, Kazuhito Sakata , Morimasa Tomikawa, Yoshihiro Nagao, Ryuichi Kumashiro, Kenoki Ohuchida, Satoshi Ieiri and Makoto Hashizume have no conflicts of interest to disclose.

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（和文抄録）

内視鏡外科手術における Bi-Hand Coordination 技術評価系に関する研究

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1. はじめに

内視鏡外科手術は従来の開腹手術に比べ切開創が小さく術後回復が早いため，患者に対して利点が多い[1)]．他方，術具の操作性が低く，術者にとって負担が大きい上に，高度な技術が要求される．このことから，内視鏡外科手術における手術トレーニングの必要性が認識されつつある．最も一般的なトレーニング方法としてボックストレーナーを用いたトレーニングが挙げられるが[2)]，手術手技の客観的な評価系が確立されていないため，指導者が付き添っていない場合，独善的なトレーニングになってしまうことが懸念される．今回我々は Bi-Hand Coordination 技術（BHC 技術）が内視鏡外科手術を安全かつ効率的に行う上で重要であることに注目し，それ客観的評価システムを考案したので報告する．

2. 手法

2.1 対象

コントロール群として内視鏡外科手術経験数 500 例以上の医師 7 名（Expert 群）と対照群の内視鏡外科手術未経験の医学部生 20 名（Novice 群）を被験者とした．

2.2 技術評価モデル

BHC 技術を評価するために，滑りやすい台座上にそれぞれ異なる方向に開閉するジッパーを設置したトレーニングモデルを用いた評価タスクを考案した．モデルと鉗子先端は磁気センサを備え，タスク中のそれぞれの軌跡を計測することが出来る．

2.3 実験方法

初めに，被験者はジッパーの操作を行わずジッパーの上を決められた順番通りになぞる（task1）．次に，開いているジッパーを順次閉じていく（task2）．

task1，task2 とも開始から完遂までの時間および台座と鉗子の軌跡をそれぞれ計測した．

2.4 評価方法および評価関数

第 1 の評価として両群間における task2 の鉗子先端および台座の移動距離，タスクを完遂するまでの時間を比較した．第 2 の評価として，task1 における鉗子先端の軌跡と task2 における鉗子先端の軌跡の差分 dI と task2 における台座の軌跡 DS の相関関係から回帰直線を算出し，Expert 群における回帰直線を基準に評価タスク結果を点数化した．評価スコア S は技術点 $S_I \leqq 50$，時間点として $S_T \leqq 50$ 合計 100 点満点とした．技術点 S_F は Expert 群における最小 dI をとる相関関数上の点 R から切片までの距離 l_R と任付スコア対象の点 P から相関関数と垂直に交わる点から切片までの距 l_P を用い，$S_I = 50\frac{l_R}{l_P}$ と定義した．

また時間点 S_T は Expert 群における最速タイム T_E と任意の完遂時間 T_A より $S_T = 50\frac{T_E}{T_A}$ とした．

統計解析には t 検定をそれぞれ用いた．

3. 結果

Expert 群は Novice 群に比べ，鉗子先端の移動距離，台座の移動距離が有意に小さく，タスクを有意に早く完遂することができた．task1 における鉗子先端の軌跡と task2 における鉗子先端の軌跡の差分と task2 における台座の軌跡の相関関係を比較したところ両群間に相関が認めたが，Expert 群はより強い関係を示した評価タスク結果を点数化するための Expert 群における回帰直線は，相関係数 0.40（$p < 0.01$），切片-0.60，決定係数 0.92（$p < 0.01$）であった．

評価スコアは，Expert 群 61.1 ± 21.9，Novice 群 40.3 ± 15.7 であり Expert 群は有意に Novice 群より高得点であった．

4. むすび

評価システムは内視鏡外科手術における BHC 技術の客観的評価系になりうると考えられた．