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A comparison of the characteristics and precision of needle driving for right-handed pediatric surgeons between right and left driving using a model of infant laparoscopic diaphragmatic hernia repair

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Abstract

Purpose: We compared the characteristics and precision of right and left needle driving for right-handed pediatric surgeons using a laparoscopic diaphragmatic repair model.

Methods: Eighteen right-handed pediatric surgeons performed three needle driving maneuvers using both hands. We evaluated the required time and conducted an image analysis. The total path length, velocity, and acceleration of the needle driving were also evaluated.

Results: Obtained results shows the findings for the required time (sec, Rt: 310.78 ± 148.93 vs. Lt: 308.61 ± 122.53, p = 0.93), sum of needle driving balances (mm, Rt: 5.23 ± 2.44 vs. Lt: 5.05 ± 3.17, p = 0.83), the gap of the needle driving interval (Rt: 1.2 ± 0.93 vs. Lt: 2.17 ± 1.67, $p = 0.04$), total path length (mm, Rt: 594.03 ± 205.29 vs. Lt: 1641.07 ± 670.68, $p < 0.01$), and average velocity (mm/sec, Rt: 1.92 ± 0.54 vs. Lt: 5.3 ± 1.39, $p < 0.01$).

Conclusion: For right-handed pediatric surgeons, left needle driving showed almost same quality of right needle driving as regarding the precision. But left needle driving also showed too fast but not economical movement unfortunately, implying rough and risky forceps manipulation. Non-dominant hand training is necessary to avoid organ injury.

(198/Limit 200 words)

Keywords: Diaphragmatic hernia repair, Laparoscopic approach, Needle driving, Non-dominant hand

Introduction

Congenital diaphragmatic hernia cases with small defects are sometimes only diagnosed postnatally and treated by elective minimally invasive surgery (MIS) [1-2]. MIS has been gradually introduced for CDH in neonates and infants because of recent advances in endoscopic surgery [3-6].

Late-presenting CDH has been treated via both thoracoscopic and laparoscopic approaches **[7-9]**. In cases with no herniation of the spleen into the thoracic cavity, a laparoscopic approach is easier to use when repairing the diaphragm because of the lack of costal restriction and a wider working space than with the thoracic approach. In particular, the abdominal cavity of infants under pneumoperitoneum is larger than those of neonates. Furthermore, handling the organs and needle driving is easier in infants than in neonates with a laparoscopic approach.

In order to close defects of the diaphragm via the abdominal approach, a parallel port layout along the diaphragm aspect is important, as the diaphragm is fixed and difficult to move, hampering adjustment of the needle driver. Needle driving is easier with endoscopic surgery than open surgery because the axis of the needle driver is fixed to the body wall through a trocar. As such, non-dominant-hand needle driving is not technically impossible. We considered the feasibility of either-hand needle driving trocar positions from a laparoscopic approach for late-presenting diaphragmatic hernia. The aim of this study was to compare the characteristics and precision of needle driving for right-handed pediatric surgeons between right (Rt) and left (Lt) needle driving using an infant laparoscopic diaphragmatic repair model simulator.

Methods

The laparoscopic diaphragmatic hernia repair simulator with a surgical skill validation system

We developed this evaluation model in collaboration with Kyoto Kagaku Co., Ltd. We developed and reported a 1-year-old infant body model (body weight 10 kg) based on computed tomography (CT) data and reproduced a pneumoperitoneum body model based on the clinical situation, as shown in Fig. 1a [10]. A detachable diaphragm with a defect (typical Bochdalek hernia, 3.0 × 1.5 cm in size), stomach, liver, and spleen were placed in this model (Fig. 1b).

Fig.1a

Fig.1b

The liver and spleen were made of urethane, and the stomach was made of styrene ($C_6H_5CH=CH_2$). The pneumoperitoneum model was covered with synthetic skin. A 30° scope 5 mm in diameter was fixed using an arm. TrackSTAR (Northern Digital Inc., Ontario, Canada) was used as the three-dimensional position measuring instrument and placed on the thoracic side of the model to trace the tips of the needle driver. The right and left needle drivers had sensors mounted on the tips, and their paths were traced on a computer with an electromagnetic tracking system, as was reported previously [11].

Tasks for participants

The participants had to perform three needle driving maneuvers each for a defect of the diaphragm using their dominant and non-dominant hands. Right needle driving used the port layout shown in Figure 2a (trocar for the needle driver at the left upper lateral abdomen, trocar for the assistant needle holder at the right abdomen near the umbilicus, and trocar for the scope at the umbilicus). Left needle driving used the port layout shown in Figure 2b (trocar for the needle driver at the right upper abdomen, trocar for the assistant needle holder at the left abdomen, and trocar for the scope at the umbilicus).

Fig.2a

Fig.2b

The participants used a 5-mm needle driver and 5-mm assistant needle holder (Karl Storz, Tuttlingen, Germany). The suture material for each maneuver was an SH-1 curved needle with 6 cm of black silk (Ethicon Endosurgery, Cincinnati, OH, USA). The participants were only required to perform needle driving, not knot tying. After completion of the task, each participant’s skills were evaluated using objective assessment points.

Study participants

A total of 18 pediatric surgeons (all right-handed) belonging to the Department of Pediatric Surgery at Kagoshima University participated in this study. None had performed laparoscopic CDH repair before. All participants had experienced less than 100 cases of endoscopic surgeries. The Research Ethics Committee for Graduate School of Medical and Dental Sciences of Kagoshima University approved this experimental study (registration number: 635). All participants provided their informed consent.

The assessment points

The assessment points were as follows, improving upon the methods previously reported by Jimbo et al. [12, 13]:

1. Time required to complete the task

   The time spent holding the three needle drivers, which was defined as the performance time from the start to completion of task, was measured in seconds.

2. Suture balance of the upper and lower side of the diaphragmatic defect for the three maneuvers

   The suture balance was measured using an image analysis software program with a USB camera connected to a computer. The sum of the bilateral gap in each needle driving maneuver (|a – a’|+ |b – b’| + |c – c’|, Fig. 3) was calculated and evaluated as the symmetry **Fig.3** of the placement of the points. A smaller gap was deemed a superior outcome.

3. Suture interval between the three maneuvers

   The suture intervals between the first and second and the second and third maneuver were measured using an image analysis software program with a USB camera connected to a computer. The gap in the suturing interval was measured (|d – d’|, Fig. 3). A smaller gap **Fig.3** was deemed superior to the pitch of needle driving, which was measured in the task. This value was monitored by the image analysis system connected to a computer.

4. Sum of the total path length of the forceps

   The total path length of the forceps was considered to be the total spatial movement measured in the task in millimeters (mm) and was determined using the TrackSTAR system.

5. Average velocities of both forceps tips

   The average velocity of each tip of the forceps was measured using the TrackSTAR system and defined as the velocity for each 0.05 s in the task.

Statistical analyses

All data are expressed as the mean ± standard deviation. Two-tailed paired and unpaired Student's *t*-tests and analyses of variance were conducted for comparisons using the JMP® 11.0 statistical software program (SAS Institute Inc., Cary, NC, USA). All data were defined as being statistically significant at p values <0.05.

Results

All participants completed the task. All participants completely performed all tasks in each port layout using both hand.

Time required to complete the task

Figure 4a shows the time required to complete the tasks: 310.78 ± 148.93 sec for right needle driving and 308.61 ± 122.53 sec for left needle driving. There were no significant differences in this duration between right and left needle driving (p = 0.93).

Fig.4a

Suture balance of the upper and lower side for the three maneuvers

The upper and lower side suturing balance was measured and calculated to determine the sum of the gap in each suture ligature in the task (Fig. 4b). The sum of the gaps for the

Fig.4b

upper and lower side balance was 5.23 ± 2.44 mm for right needle driving and 5.05 ± 3.17 mm for left needle driving. There were no significant differences in the balance between right and left needle driving ($p = 0.83$).

Suture interval between the three maneuvers

The suture interval of the first and second and of the second and third maneuver were measured and calculated as shown in Figure 4c. The interval was 1.2 ± 0.93 mm for right needle driving and 2.17 ± 1.67 mm for left needle driving. Right needle driving was significantly superior to left needle driving ($p = 0.04$). **Fig.4c**

Sum of the total path length of the forceps

The total path length for both needle driving approaches is shown in Figure 5a. The length was 594.03 ± 205.29 mm for right needle driving and 1641.07 ± 670.68 mm for left needle driving. The total path length for left needle driving was significantly longer than for right needle driving ($p < 0.01$). **Fig.5a**

Average velocities with both needle driving approaches

The average velocity with both needle driving approaches is shown in Figure 5b. The average velocity was 1.92 ± 0.54 mm/sec for right needle driving and 5.3 ± 1.39 mm/sec for left needle driving. The average velocity for left needle driving was significantly faster than for right needle driving ($p < 0.01$). **Fig.5b**

Discussion

In this study, we attempted to compare for the first time the characteristics and precision of needle driving for right-handed pediatric surgeons between right and left needle driving using a model of infant laparoscopic diaphragmatic hernia repair. We newly developed a diaphragmatic hernia simulator using a previously reported pneumoperitoneum body model.

We used four assessment points to evaluate the endoscopic surgical skills of the participants, as described in our previous report [10-13].

We made several major findings in the present study. First, we developed a novel laparoscopic diaphragmatic hernia repair simulator with a pneumoperitoneum body model for the objective assessment of endoscopic surgical skills. No papers with similar achievements were found in a literature search. Second, right-handed pediatric surgeons successfully completed both right and left needle driving maneuvers using our model. Third, there were no significant differences in the time required for the task between the right and left needle driving approaches. Fourth, regarding the needle driving precision, there were no significant differences in the suturing balance between the right and left needle driving approaches. However, the right needle driving approach was significantly superior to the left needle driving approach in the suturing interval. Finally, the total path length was significantly longer and the average velocity significantly faster with the left needle driving approach than the right needle driving approach.

Whether or not a laparoscopic approach for congenital diaphragmatic hernia should be selected depends on the pathophysiologic state and severity [14, 15]. In general, there is a greater need for ambidextrous coordination in endoscopic surgery than with open procedures. Suturing, including needle driving, is one of the most difficult and complicated techniques that are performed during endoscopic surgery. However, the rotation of the needle driver is the most important aspect of the needle driving procedure; we therefore assumed that needle driving in endoscopic surgery was easier than with open surgery because the axis of the needle driver is fixed to the body wall through a trocar. In the present study, we compared the characteristics and precision of needle driving for right-handed pediatric surgeons between right and left driving approaches.

The time required and precision achieved with suturing with non-dominant (left)-hand needle driving were almost the same as those with dominant (right)-hand needle driving, results that were expected before performing the study. Surgeons were able to perform needle driving with equivalent skill in endoscopic surgery, regardless of the hand used, due to the fixation of the axis.

However, the total path length and average velocity with non-dominant (left)-hand needle driving were longer and faster than those with dominant (right)-hand needle driving. Initially, we suspected that surgeons would not be able to manipulate the needle driver effectively using the non-dominant hand. The results of this study indicate that control of forceps manipulation, including needle driving, using the non-dominant hand was more difficult than using the dominant hand. Non-dominant hand driving showed fast but not economical movement. Tanoue K et al. [16] reported the relation between training effect and surgical errors. They found that average velocity of forceps was increased after the training. But they also found that surgical errors were increased during the fast manipulation of the forceps in box tasks after the training. Ieiri S et al. [17] also reported that shorter path length and slow manipulation increased the quality of endoscopic procedures. These results suggest that performing needle driving using the non-dominant hand is risky in pediatric endosurgery. Pediatric surgeons must be gentle when performing maneuvers and take particular care with patients' fragile organs. A previous report suggested that pediatric surgeons were able to perform endoscopic procedures with the same quality as general surgeons in short-term training [**17**-19]. In addition, Tomikawa M et al [13] showed the effectiveness of training for both spatial path lengths and average tip speeds of the needle holders. Especially in the left hand, they found significant improvements in the spatial path lengths and average tip speeds.

In conclusion, for right-handed pediatric surgeons, left needle driving showed too fast but not economical movement, implying rough and risky forceps manipulation in a small working space (e.g. neonates and infant patients). These results suggest that non-dominant hand training is necessary for advanced pediatric endosurgery to avoid organ injury due to fast and excessive forceps manipulation.

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Conflict of interest: No competing financial interests exist.

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Legend for Figure

Figure 1.

a) Three-dimensional image of the pediatric pneumoperitoneum body model and detachable diaphragm using computer-aided drawing.

b) The laparoscopic view of the simulator. The liver, spleen, and stomach were placed in the abdominal cavity of the pneumoperitoneum body model. A Bochodalek hernia was depicted as in a clinical situation. Defect size: 1.5 × 3.0 cm

Figure 2.

a) A schematic illustration showing the port layout of the simulator and a laparoscopic view of the right needle driving situation. The port layout was as follows: a trocar for the needle driver at the left upper lateral abdomen, trocar for the assistant needle holder at the right abdomen near the umbilicus, and trocar for the scope at the umbilicus.

b) A schematic illustration showing the port layout of the simulator and a laparoscopic view of the left needle driving situation. The port layout was as follows: a trocar for the needle driver at the right upper abdomen, trocar for the assistant needle holder at the left abdomen, and trocar for the scope at the umbilicus.

Figure 3.

The sum of the gap of the upper and lower widths of suturing and the gap of the suturing interval was calculated.

Figure 4.

a) Time required to complete the task for right and left needle driving.

b) The sum of the gaps of the upper and lower suturing widths. The right and left side suturing balance of the wrap was measured and calculated to give the sum of the gap between each suture ligature in the task.

c) The sum of the gaps of the suturing interval between the three needle driving maneuvers. The pitch of the three needle driving maneuvers was measured in the task.

Figure 5.

a) The total path length for right and left needle driving.

b) The average velocity for right and left needle driving.

Figure 1

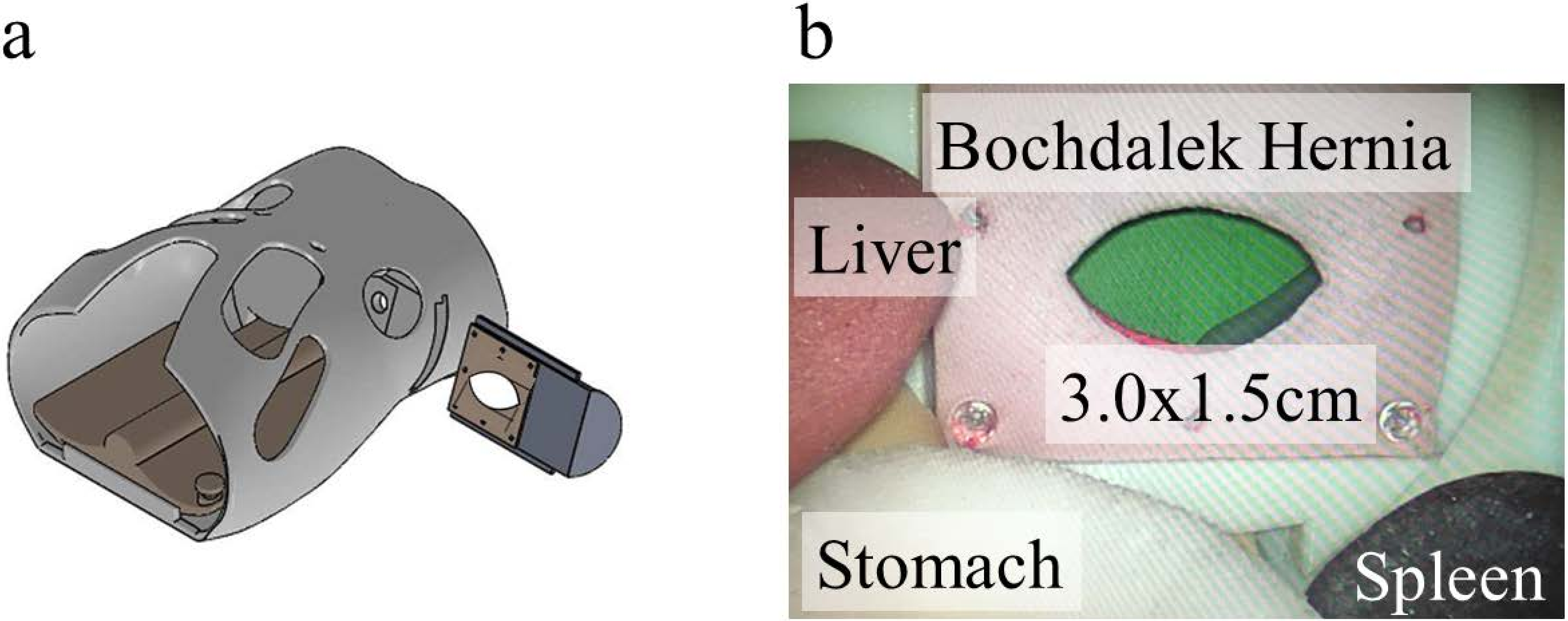
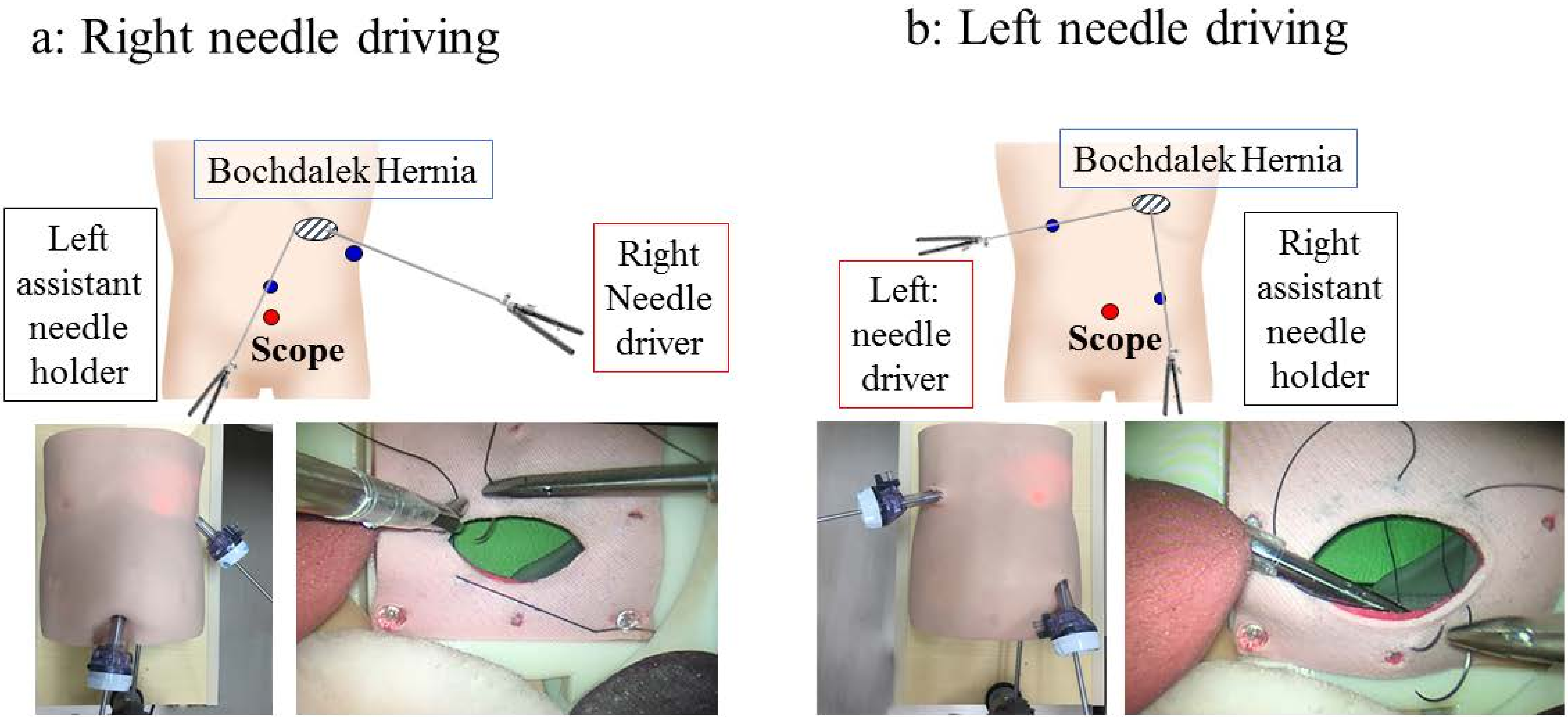


Figure 2



a: Right needle driving
Bochdalek Hernia
Left assistant needle holder
Right Needle driver
Scope
b: Left needle driving
Bochdalek Hernia
Left: needle driver
Right assistant needle holder
Scope

Figure 3

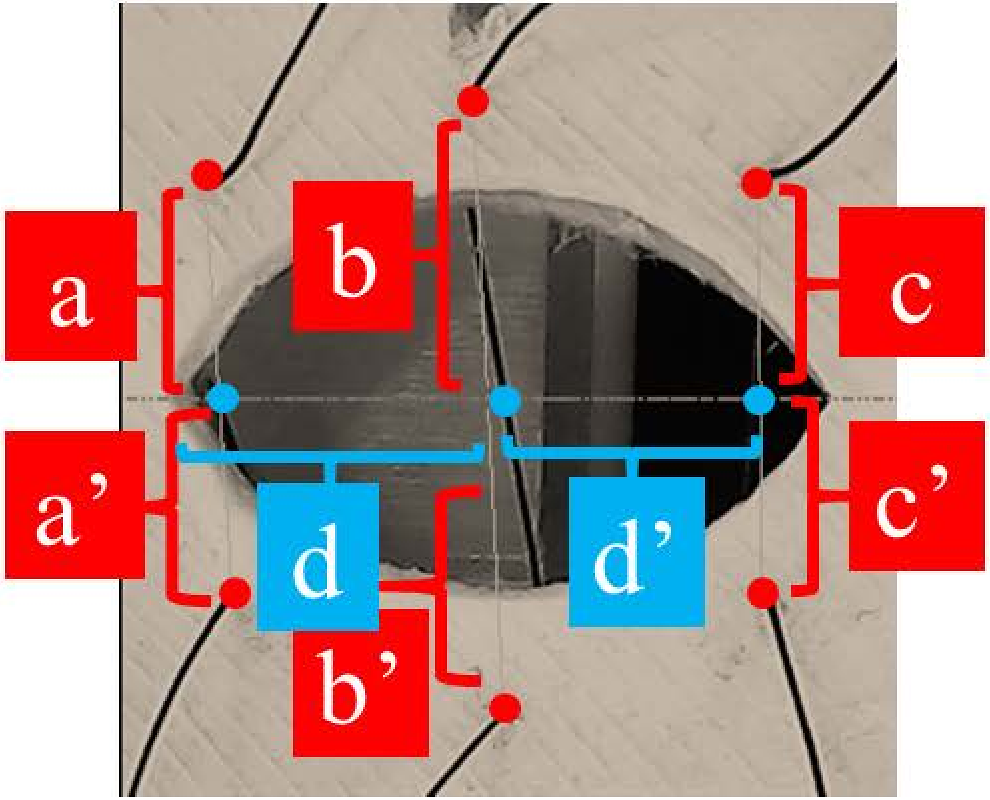


Figure 4

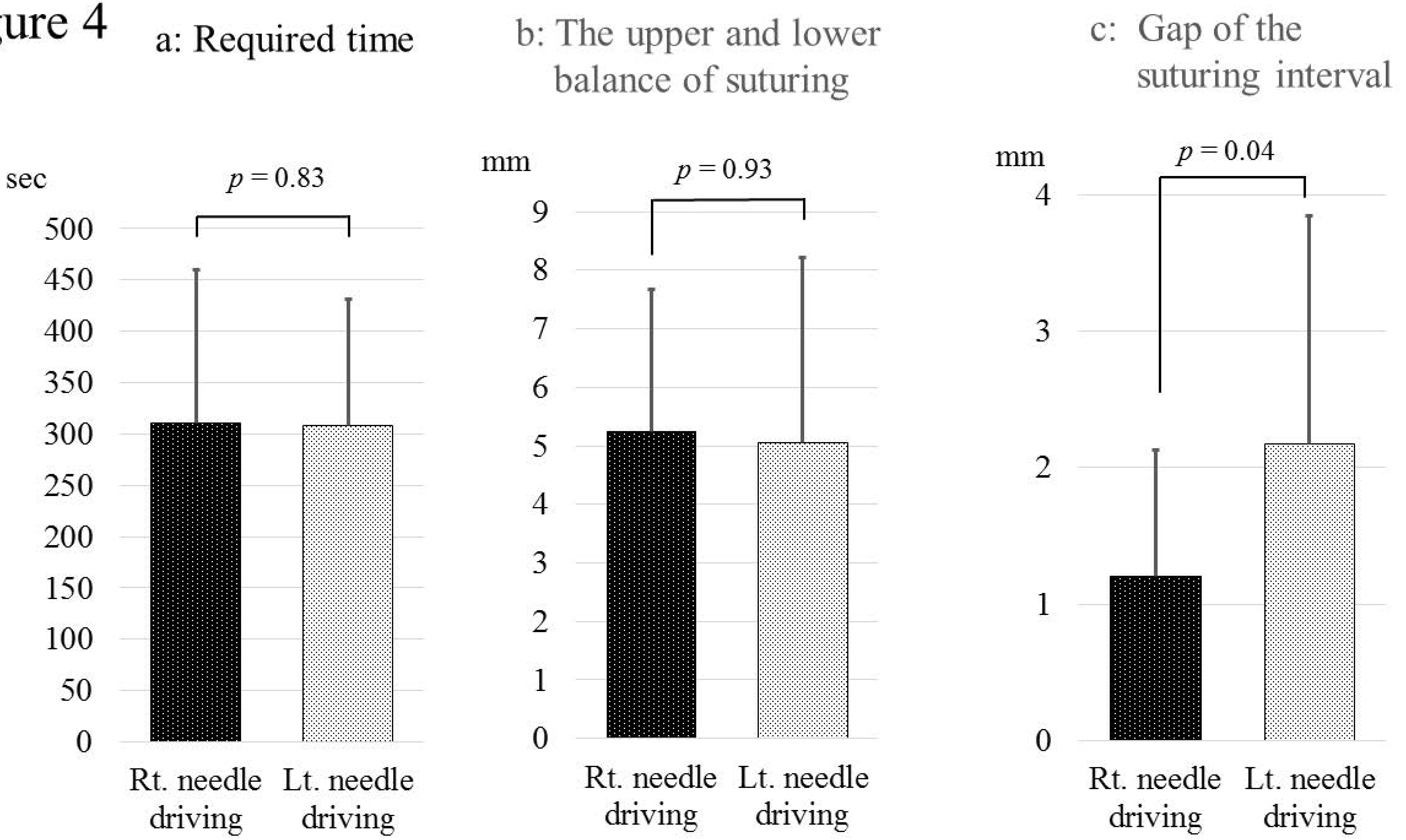
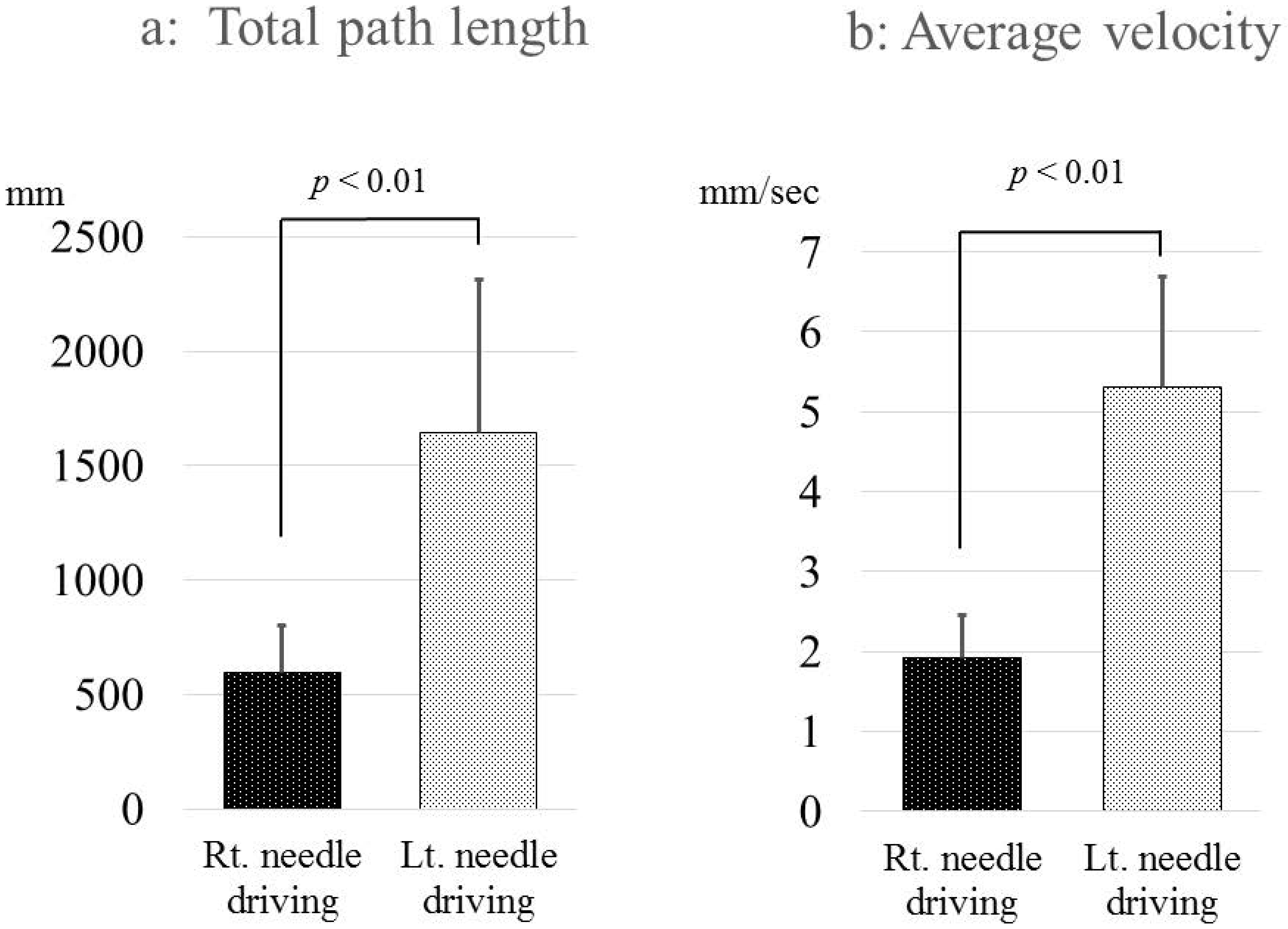

a: Required time
sec
p = 0.83
500
450
400
350
300
250
200
150
100
50
0
Rt. needle driving
Lt. needle driving
b: The upper and lower balance of suturing
mm
p = 0.93
9
8
7
6
5
4
3
2
1
0
Rt. needle driving
Lt. needle driving
c: Gap of the suturing interval
mm
p = 0.04
4
3
2
1
0
Rt. needle driving
Lt. needle driving

Figure 5


a: Total path length
mm
p < 0.01
2500
2000
1500
1000
500
0
Rt. needle driving
Lt. needle driving
b: Average velocity
mm/sec
p < 0.01
7
6
5
4
3
2
1
0
Rt. needle driving
Lt. needle driving