

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

| | |
|------------------------------|---|
| 著者 | 池江 隆正 |
| journal or publication title | Pediatric Surgery International |
| volume | 33 |
| number | 10 |
| page range | 1103-1108 |
| year | 2017-10 |
| ファイル(説明) | 博士論文全文 最終試験結果の要旨 論文審査の要旨 博士論文要旨 |
| 別言語のタイトル | 右利きの小児外科医における右手と左手の運針の特性、精確性の比較：横隔膜ヘルニアの腹腔鏡手術モデルを用いた検討 |
| 学位授与番号 | 17701乙総論第32号 |
| URL | http://hdl.handle.net/10232/00030432 |

doi: 10.1007/s00383-017-4144-x

1 **Title Page (Revised Manuscript: Original Article PSI-JSPS Issue)**

2
3 **A comparison of the characteristics and precision of needle driving for right-handed**
4 **pediatric surgeons between right and left driving using a model of infant laparoscopic**
5 **diaphragmatic hernia repair**
6

7 **Authors:**

8 Takamasa IKEE, Shun ONISHI, Motoi MUKAI, Takafumi KAWANO, Koshiro SUGITA,
9 Tomoe MORIGUCHI, Koji YAMADA, Waka YAMADA, Ryuta MASUYA,
10 Seiro MACHIGASHIRA, Kazuhiko NAKAME, Tatsuru KAJI, Satoshi IEIRI
11

12 *** Takamasa IKEE and Shun ONISHI contributed equally to this work.**
13

14 **Affiliation:**

15 Department of Pediatric Surgery, Research Field in Medical and Health Sciences,
16 Medical and Dental Area, Research and Education Assembly, Kagoshima University,
17 Kagoshima, JAPAN
18
19

20 **Corresponding Author: Satoshi IEIRI, M.D., Ph.D.**

21 Department of Pediatric Surgery, Research Field in Medical and Health Sciences,
22 Medical and Dental Area, Research and Education Assembly, Kagoshima University
23 Address: 8-35-1, Sakuragaoka, Kagoshima City, JAPAN, 890-8520

24 TEL: +81-99-275-5444, FAX: +81-99-275-2628

25 E-mail: sieiri@m.kufm.kagoshima-u.ac.jp
26

1 **Abstract**

2

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

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

8 **Results:** Obtained results shows the findings for the required time (sec, Rt: 310.78 ± 148.93
9 vs. Lt: 308.61 ± 122.53 , $p = 0.93$), sum of needle driving balances (mm, Rt: 5.23 ± 2.44 vs. Lt:
10 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 ,
11 $p = 0.04$), total path length (mm, Rt: 594.03 ± 205.29 vs. Lt: 1641.07 ± 670.68 , $p < 0.01$), and
12 average velocity (mm/sec, Rt: 1.92 ± 0.54 vs. Lt: 5.3 ± 1.39 , $p < 0.01$).

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

17 (198/Limit 200 words)

18

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

21

1 **Introduction**

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

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

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

23

24 **Methods**

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

26 We developed this evaluation model in collaboration with Kyoto Kagaku Co., Ltd. We

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

Fig.1a

Fig.1b

5 The liver and spleen were made of urethane, and the stomach was made of styrene
6 ($C_6H_5CH=CH_2$). The pneumoperitoneum model was covered with synthetic skin. A 30° scope
7 5 mm in diameter was fixed using an arm. TrackSTAR (Northern Digital Inc., Ontario, Canada)
8 was used as the three-dimensional position measuring instrument and placed on the thoracic
9 side of the model to trace the tips of the needle driver. The right and left needle drivers had
10 sensors mounted on the tips, and their paths were traced on a computer with an electromagnetic
11 tracking system, as was reported previously [11].

13 *Tasks for participants*

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

Fig.2a

Fig.2b

21 The participants used a 5-mm needle driver and 5-mm assistant needle holder (Karl Storz,
22 Tuttlingen, Germany). The suture material for each maneuver was an SH-1 curved needle with
23 6 cm of black silk (Ethicon Endosurgery, Cincinnati, OH, USA). The participants were only
24 required to perform needle driving, not knot tying. After completion of the task, each
25 participant's skills were evaluated using objective assessment points.

1 *Study participants*

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

8

9 *The assessment points*

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

12 1. Time required to complete the task

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

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

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

Fig.3

21 3. Suture interval between the three maneuvers

22 The suture intervals between the first and second and the second and third maneuver were
23 measured using an image analysis software program with a USB camera connected to a
24 computer. The gap in the suturing interval was measured ($|d - d'|$, Fig. 3). A smaller gap
25 was deemed superior to the pitch of needle driving, which was measured in the task. This

Fig.3

1 value was monitored by the image analysis system connected to a computer.

2 4. Sum of the total path length of the forceps

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

5 5. Average velocities of both forceps tips

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

8

9 *Statistical analyses*

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

14

15 **Results**

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

18

19 *Time required to complete the task*

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

23

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

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

Fig.4a

Fig.4b

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

4

5 *Suture interval between the three maneuvers*

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

10

11 *Sum of the total path length of the forceps*

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

16

17 *Average velocities with both needle driving approaches*

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

22

23

24 **Discussion**

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

1 a diaphragmatic hernia simulator using a previously reported pneumoperitoneum body model.

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

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

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

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

6 However, the total path length and average velocity with non-dominant (left)-hand
7 needle driving were longer and faster than those with dominant (right)-hand needle driving.
8 Initially, we suspected that surgeons would not be able to manipulate the needle driver
9 effectively using the non-dominant hand. The results of this study indicate that control of
10 forceps manipulation, including needle driving, using the non-dominant hand was more
11 difficult than using the dominant hand. Non-dominant hand driving showed fast but not
12 economical movement. Tanoue K et al. [16] reported the relation between training effect and
13 surgical errors. They found that average velocity of forceps was increased after the training.
14 But they also found that surgical errors were increased during the fast manipulation of the
15 forceps in box tasks after the training. Ieiri S et al. [17] also reported that shorter path length
16 and slow manipulation increased the quality of endoscopic procedures. These results suggest
17 that performing needle driving using the non-dominant hand is risky in pediatric endosurgery.
18 Pediatric surgeons must be gentle when performing maneuvers and take particular care with
19 patients' fragile organs. A previous report suggested that pediatric surgeons were able to
20 perform endoscopic procedures with the same quality as general surgeons in short-term training
21 [17-19]. In addition, Tomikawa M et al [13] showed the effectiveness of training for both
22 spatial path lengths and average tip speeds of the needle holders. Especially in the left hand,
23 they found significant improvements in the spatial path lengths and average tip speeds.

24 In conclusion, for right-handed pediatric surgeons, left needle driving showed too fast
25 but not economical movement, implying rough and risky forceps manipulation in a small

1 working space (e.g. neonates and infant patients). These results suggest that non-dominant hand
2 training is necessary for advanced pediatric endosurgery to avoid organ injury due to fast and
3 excessive forceps manipulation.

4

5 **Acknowledgments**

6 We thank Brian Quinn for his comments and help with the manuscript. This study was
7 supported by Grants-in-Aid for Scientific Research from the Japan Society for the Promotion
8 of Science (JSPS, No. 25293360, No. 26670765, No. 16K11350), Research Grant from the
9 Japanese Foundation for Research and Promotion of Endoscopy (JFE), Research Grant from
10 the Japanese Foundation for Research and Promotion of Endoscopy (J-CASE), Research Grant
11 from President's Discretionary Expenses of Kagoshima University, Research Grant from
12 Foundation for Promotion of Cancer Research, Research Grant from Foundation for Shinnihon
13 Zaidan, Research Grant from Tateishi Science and Technology Foundation, Research Grant
14 from The UBE Foundation, Research Grant from Mitsui Life Social Welfare
15 Foundation, Research Grant from Suzuken Memorial Foundation, Research Grant from
16 Princess Takamatsu Research Foundation, Research Grant (The Kurata Grants) from the
17 Hitachi Global Foundation and Research Grant from the Japanese Society for Medical and
18 Biological Engineering.

19

20 **Conflict of interest:** No competing financial interests exist.

21

1 **References**

- 2 1. Terui K, Nagata K, Ito M, Yamoto M, Shiraishi M, Taguchi T, Hayakawa M, Okuyama H,
3 Yoshida H, Masumoto K, Kanamori Y, Goishi K, Urushihara N, Kawataki M, Inamura N,
4 Kimura O, Okazaki T, Toyoshima K, Usui N (2015) Surgical approaches for neonatal
5 congenital diaphragmatic hernia: a systematic review and meta-analysis. *Pediatr Surg Int.*
6 31(10):891-7. doi: 10.1007/s00383-015-3765-1. Review.
- 7 2. Arca MJ, Barnhart DC, Lelli JL, Greenfeld J, Harmon CM, Hirschl RB, Teitelbaum DH
8 (2003) Early experience with minimally invasive repair of congenital diaphragmatic
9 hernias: results and lessons learned. *J Pediatr Surg* 38(11):1563-1568
- 10 3. Okazaki T, Okawada M, Koga H, Miyano G, Doi T, Ogasawara Y, Yamataka A (2016)
11 Congenital diaphragmatic hernia in neonates: factors related to failure of thoracoscopic
12 repair. *Pediatr Surg Int.* 32(10):933-7. doi: 10.1007/s00383-016-3947-5.
- 13 4. Putnam LR, Tsao K, Lally KP, Blakely ML, Jancelewicz T, Lally PA, Harting MT (2016)
14 Minimally Invasive vs Open Congenital Diaphragmatic Hernia Repair: Is There a Superior
15 Approach? Congenital Diaphragmatic Hernia Study Group and the Pediatric Surgery
16 Research Collaborative. *J Am Coll Surg.* 2017 Jan 29. pii: S1072-7515(17)30120-5. doi:
17 10.1016/j.jamcollsurg.2016.12.050
- 18 5. Liem NT (2003) Thoracoscopic surgery for congenital diaphragmatic hernia: a report of
19 nine cases. *Asian J Surg* 26(4):210-212
- 20 6. Nguyen TL, Le AD (2006) Thoracoscopic repair for congenital diaphragmatic hernia:
21 lessons from 45 cases. *J Pediatr Surg* 41(10):1713-1715
- 22 7. Van der Zee DC, Bax NM (1995) Laparoscopic repair of congenital diaphragmatic hernia
23 in a six-month-old child. *Surg Endosc* 9:1001-1003
- 24 8. Taskin M, Zengin K, Unal E, Eren D, Korman U (2002) Laparoscopic repair of congenital
25 diaphragmatic hernias. *Surg Endosc* 16(5):869

- 1 9. Yang EY, Allmendinger N, Johnson SM, Chen C, Wilson JM, Fishman SJ (2005) Neonatal
2 thoracoscopic repair of congenital diaphragmatic hernia: selection criteria for successful
3 outcome. *J Pediatr Surg* 40(9):1369-1375
- 4 10. Jimbo T, Ieiri S, Obata S, Uemura M, Souzaki R, Matsuoka N, Katayama T, Masumoto K,
5 Hashizume M, Taguchi T (2015) Effectiveness of short-term endoscopic surgical skill
6 training for young pediatric surgeons: a validation study using the laparoscopic
7 fundoplication simulator. *Pediatr Surg Int.* (10):963-9. doi: 10.1007/s00383-015-3776-y.
- 8 11. Obata S, Ieiri S, Uemura M, Jimbo T, Souzaki R, Matsuoka N, Katayama T, Hashizume M,
9 Taguchi T (2015) An endoscopic surgical skill validation system for pediatric surgeons
10 using a model of congenital diaphragmatic hernia repair. *J Laparoendosc Adv Surg Tech A.*
11 2015 Sep;25(9):775-81. doi: 10.1089/lap.2014.0259.
- 12 12. Jimbo T, Ieiri S, Obata S, Uemura M, Souzaki R, Matsuoka N, Katayama T, Masumoto K,
13 Hashizume M, Taguchi T (2017) A new innovative laparoscopic fundoplication training
14 simulator with a surgical skill validation system. *Surg Endosc.* 31(4):1688-1696. doi:
15 10.1007/s00464-016-5159-4.
- 16 13. Tomikawa M, Uemura M, Kenmotsu H, Konishi K, Ohuchida K, Okazaki K, Ieiri S,
17 Tanoue K, Hashizume M (2015) Evaluation of the 10-year history of a 2-day standardized
18 laparoscopic surgical skills training program at Kyushu University. *Surg Today.*
19 doi:10.1007/s00595-015-1227-y
- 20 14. Lima M, Lauro V, Donum M, Libri M, Bertozzi M, Pigna A, D'Amico R (2001) Laparoscopic
21 surgery of diaphragmatic diseases in children: our experience with five cases. *Eur J Pediatr*
22 *Surg* 11:377-381
- 23 15. Shah AV, Shah AA (2002) Laparoscopic approach to surgical management of congenital
24 diaphragmatic hernia in the newborn. *J Pediatr Surg* 37:548-550
- 25 16. Tanoue K, Ieiri S, Konishi K, Yasunaga T, Okazaki K, Yamaguchi S, Yoshida D, Kakeji Y,

- 1 Hashizume M (2008) Effectiveness of endoscopic surgery training for medical students
2 using a virtual reality simulator versus a box trainer: a randomized controlled trial. *Surg*
3 *Endosc.* 22(4):985-90.
- 4 17. Ieiri S, Nakatsuji T, Higashi M, Akiyoshi J, Uemura M, Konishi K, Onimaru M, Ohuchida
5 K, Hong J, Tomikawa M, Tanoue K, Hashizume M, Taguchi T (2010) Effectiveness of
6 basic endoscopic surgical skill training for pediatric surgeons. *Pediatr Surg Int.* 2010
7 Oct;26(10):947-54. doi: 10.1007/s00383-010-2665-7.
- 8 18. Hopper AN, Jamison MH, Lewis WG (2007) Learning curves in surgical practice. *Postgrad*
9 *Med J* 83(986):777–779. doi:10.1136/pgmj.2007.057190
- 10 19. Beyer-Berjot L, Palter V, Grantcharov T, Aggarwal R (2014) Advanced training in
11 laparoscopic abdominal surgery: a systematic review. *Surgery* 156(3):676–688
12

1 **Legend for Figure**

2 **Figure 1.**

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

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

8

9 **Figure 2.**

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

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

18

19 **Figure 3.**

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

22

23 **Figure 4.**

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

25 b) The sum of the gaps of the upper and lower suturing widths. The right and left side suturing

1 balance of the wrap was measured and calculated to give the sum of the gap between each
2 suture ligature in the task.

3 c) The sum of the gaps of the suturing interval between the three needle driving maneuvers.

4 The pitch of the three needle driving maneuvers was measured in the task.

5

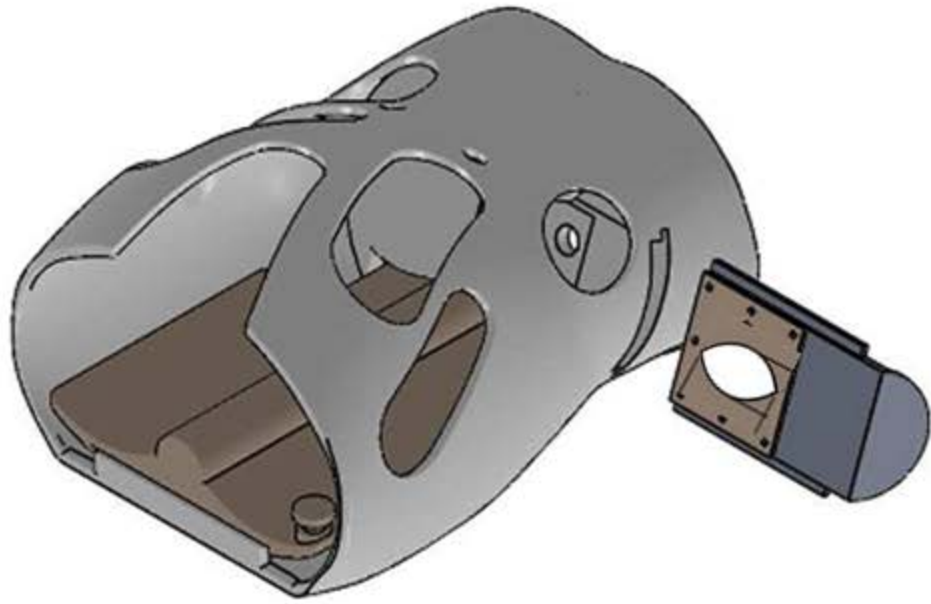
6 **Figure 5.**

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

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

Figure 1

a

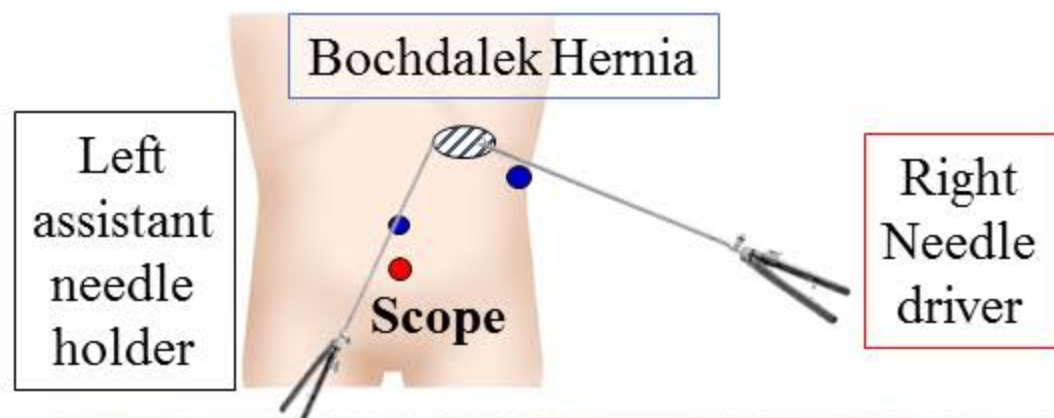


b



Figure 2

a: Right needle driving



b: Left needle driving

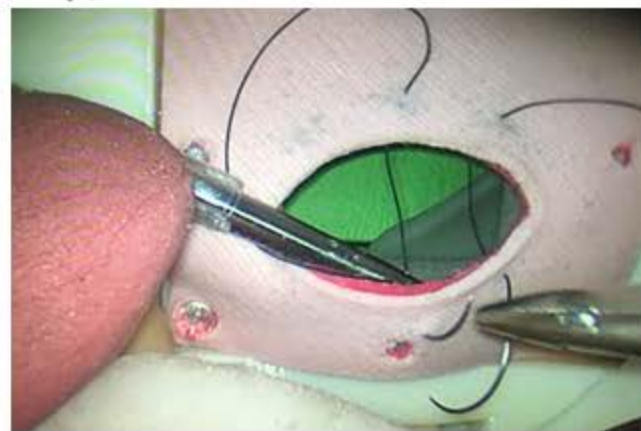
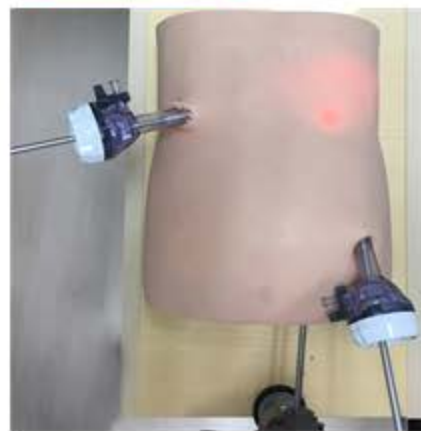
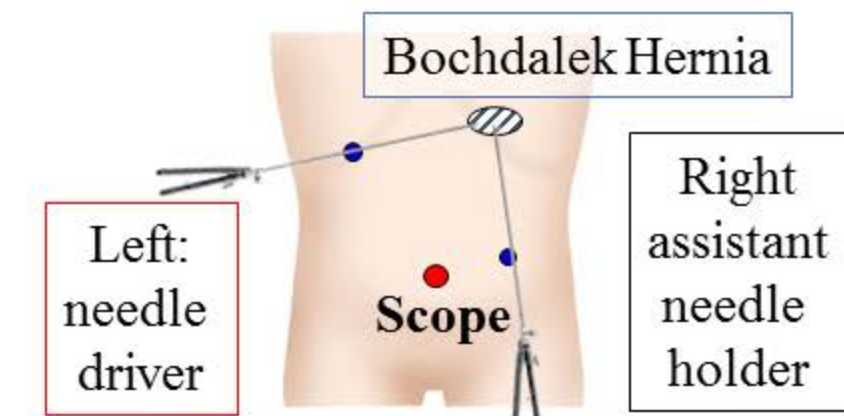


Figure 3

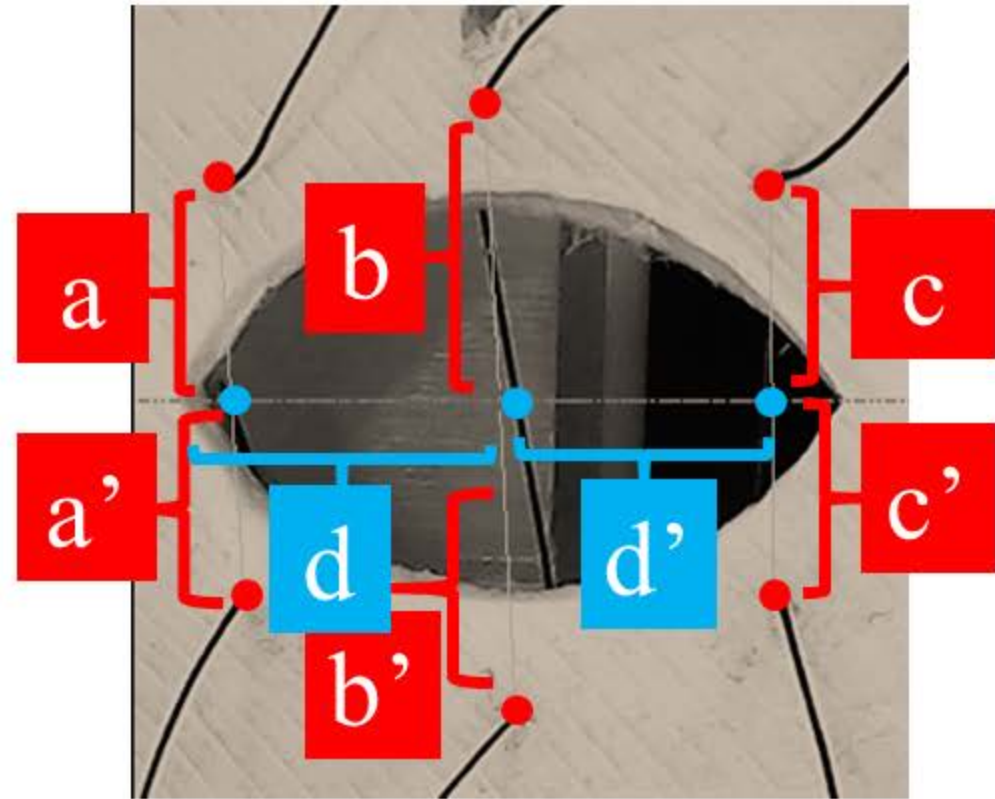
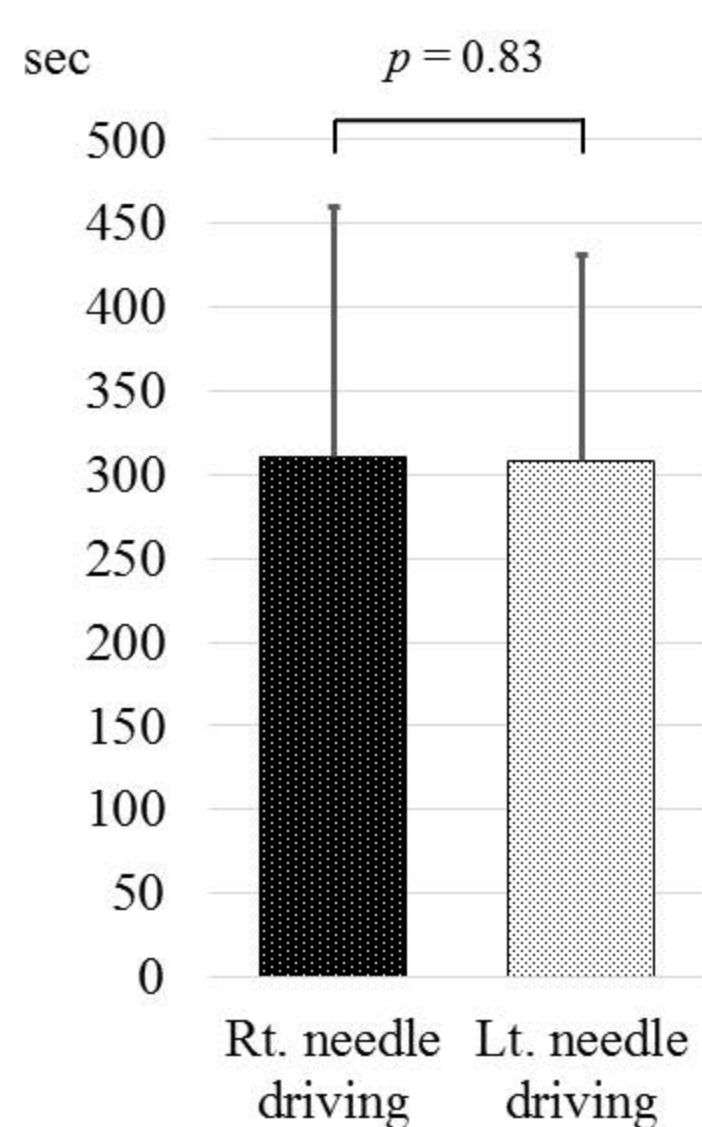
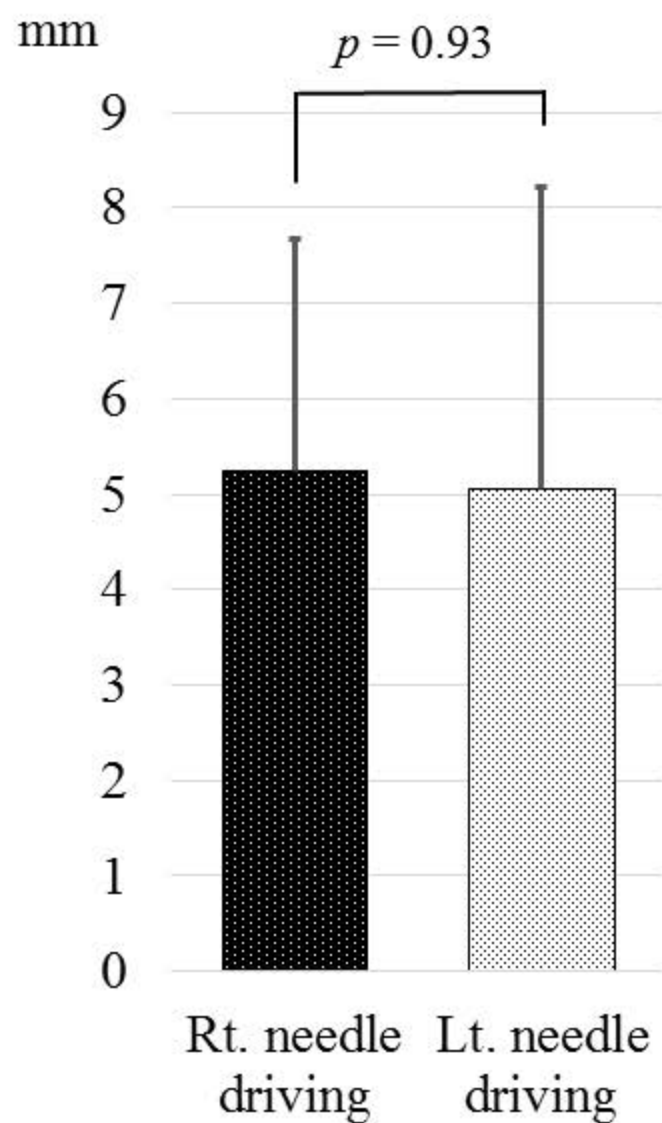


Figure 4

a: Required time



b: The upper and lower balance of suturing



c: Gap of the suturing interval

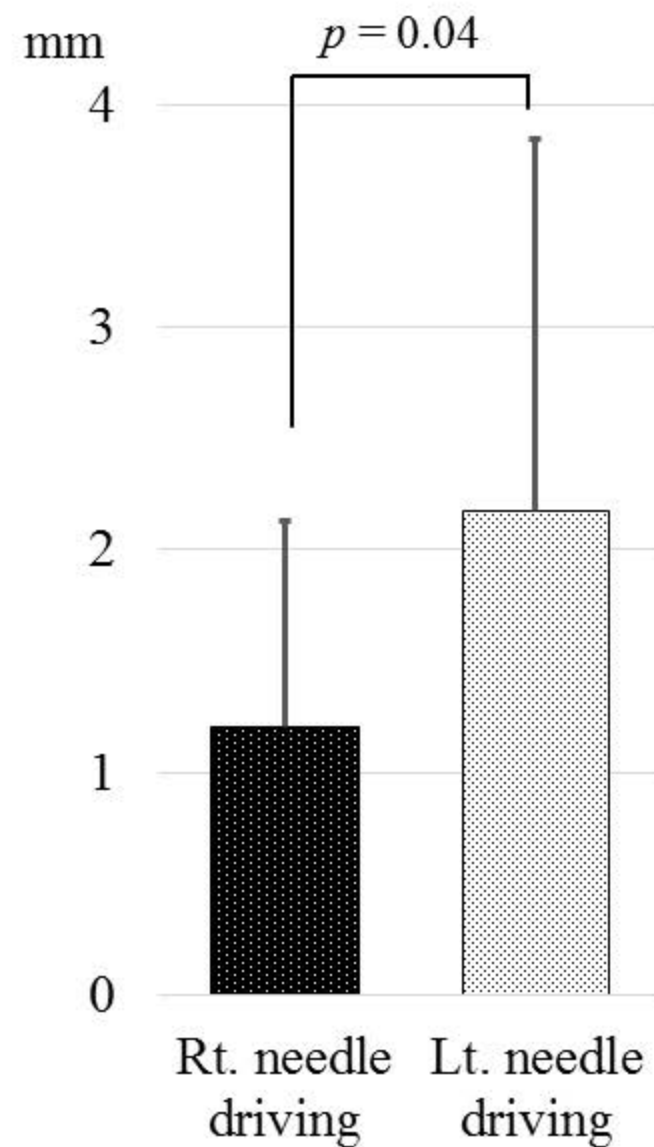
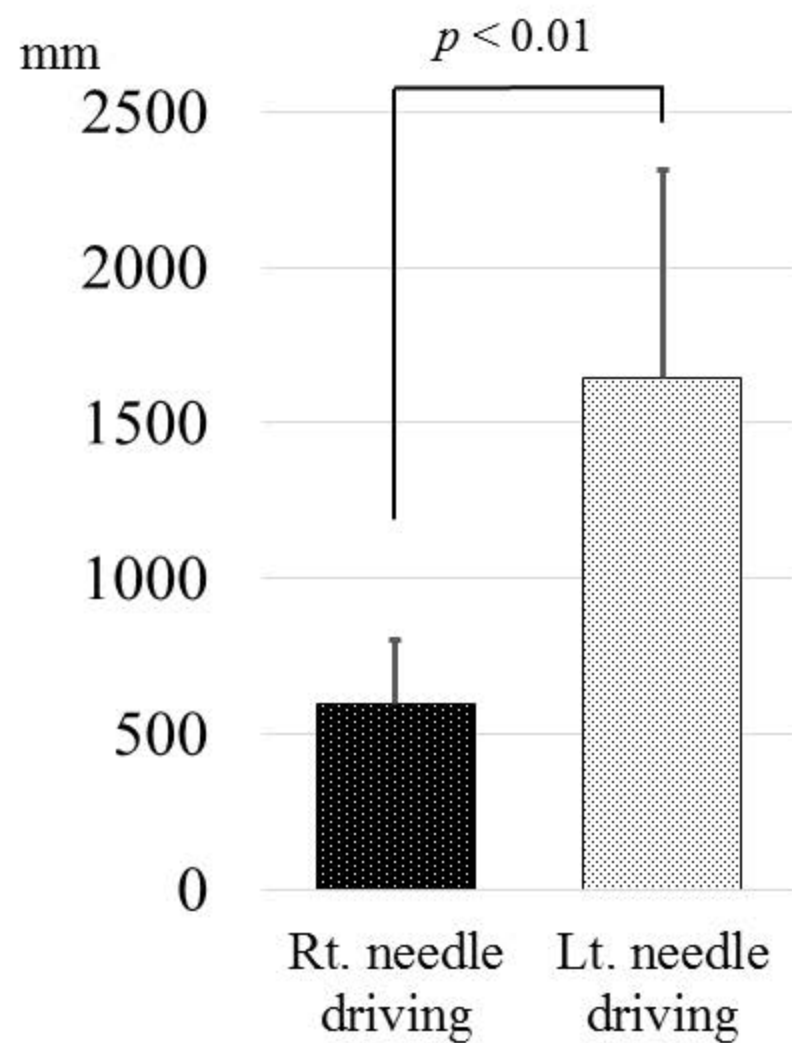


Figure 5

a: Total path length



b: Average velocity

