Utility of a Three-Dimensional Printed Pelvic Model for Lateral Pelvic Lymph Node Dissection Education: A Randomized Controlled Trial

Daisuke Hojo, MD, Koji Murono, MD, PhD, Hiroaki Nozawa, MD, PhD, Kazushige Kawai, MD, PhD, Keisuke Hata, MD, PhD, Toshiaki Tanaka, MD, PhD, Koji Oba, PhD, Soichiro Ishihara, MD, PhD

BACKGROUND: Lateral pelvic lymph node dissection for rectal cancer is a difficult technique due to the complex pelvic anatomy involved. Three-dimensional (3D) organ models have been introduced as education tools to study anatomy in some fields. In this study, we educated the participants about pelvic anatomy using a 3D model, and evaluated learning efficiency, comparing the outcomes with those using a traditional textbook.

STUDY DESIGN: This study was a randomized, controlled, single-center trial conducted between July 2018 and July 2019. A total of 102 participants (34 medical students, 34 residents, and 34 surgeons) were enrolled. Participants were randomly assigned to the 3D model group or the textbook group. First, they completed a short test to confirm their basic knowledge before further education. After collocated education, they completed the same short test again and another long test to evaluate their learning outcomes.

RESULTS: Before education, there was no significant difference in the short test scores between the 3D model group and the textbook group. After education, the short and long test scores of the 3D model group were significantly higher than those of the textbook group for students (short test; $p = 0.05$, long test; $p = 0.03$), residents (short test; $p = 0.05$, long test; $p = 0.002$), and surgeons (short test; $p = 0.009$, long test; $p < 0.001$).

CONCLUSIONS: Using a 3D pelvic model is superior to using a textbook when learning pelvic anatomy required for lateral pelvic lymph node dissection. (J Am Coll Surg 2019;229:552−559. © 2019 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

In Japan, lateral pelvic lymph node dissection (LLND) is the standard technique for treating locally advanced lower rectal cancer.[1-3] The LLND was adapted for limited cases such as recurrent or remnant metastasis[4,5] because lateral lymph node metastases are considered distant metastases. However, the prognosis for progressive lower rectal cancer with lateral lymph node metastasis was better than that of stage IV cancer after curative resection.[6] Moreover, cases treated with rectal cancer resection and LLND resulted in lower local recurrence rates than those not treated with LLND.[7] Therefore, the importance of LLND has become increasingly recognized in the West. However, LLND is a difficult technique because of the complex pelvic anatomy involved and the necessity to preserve the pelvic nerve. Therefore, learning the pelvic anatomy is important and necessary to successfully perform LLND.

Cadaveric dissection is superior to the textbook as an educational tool for learning because it allows for an understanding of the 3-dimensional (3D) relationships between the bones, muscles, vessels, and nerves.[8] However, cadaveric dissection involves issues such as a dearth of anatomic specimens;[9] therefore, whether dissection should be used for teaching anatomy is controversial.[10-12]

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International Committee of Medical Journal Editors data sharing statement available online as eTable 1.

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From the Department of Surgical Oncology, Faculty of Medicine (Hojo, Murono, Nozawa, Kawai, Hata, Tanaka, Ishihara) and the Department of Biostatistics, School of Public Health, Graduate School of Medicine (Oba), The University of Tokyo, Tokyo, Japan.

Correspondence address: Daisuke Hojo, MD, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. email: HOJOD-SUR@h.u-tokyo.ac.jp

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Abbreviations and Acronyms

LLND = lateral pelvic lymph node dissection
STL = stereolithography
3D = 3-dimensional
2D = 2-dimensional

The technology used for 3D printing was first described by Kodama in 1981.[13] A 3D printed model avoids the current ethical problems associated with dissection. Clinically, it had been used as a navigation tool for parenchymal organs such as the liver,[14] kidney,[15] and pancreas.[16] Three-dimensional printing can also be used for anatomic education. Randomized controlled trials of the heart,[17] skull,[18] and fractured spine[19] have indicated the utility of 3D printing models for medical students. However, these studies referred to educating students about only simple anatomic structures of the organs.

There is only 1 case report of a 3D model used to study pelvic anatomy.[20] In that case report, the pelvic model was used to learn about rectal cancer in women, and it clearly demonstrated the spatial relationships of the pelvic structures during laparoscopic surgery and LLND. Therefore, a 3D printed model may be useful for understanding the pelvic anatomy.

In this study, we created a 3D printed model of the pelvis for the purpose of anatomic education and evaluated the learning efficiency compared with traditional education using a 2-dimensional (2D) tool (charts and diagrams in a textbook). Moreover, we compared the efficacy of the learning tools by reviewing subjective evaluations delineated in a questionnaire that was distributed among the students, residents, and young training surgeons involved in this educational experiment.

METHODS

Development of the 3D pelvic model

We used 3D pelvic models (Fig. 1) that were created for rectal cancer patients before resection of lower rectal cancer using LLND (eFig. 1). The 3D image of the printed model was based on thin-slice images (slice thickness, 0.5 mm) obtained with enhanced multidetector CT (Aquilion ONE, Canon Medical Systems). The CT images were reconstructed from scanned data of the patients, with beam collimation of 0.5 mm × 80, using a 240-mm field of view with 512 matrix size.

Computed tomography data were exported to a Digital Imaging and Communications in Medicine (DICOM) file. To generate the 3D virtual model, each organ structure was segmented by a colorectal surgeon familiar with the anatomy required for LLND together with an expert of radiologist and converted to a stereolithography (STL) file using the OsiriX MD viewer (Pixmeo Sarl)[21,22] and Meshmixer (version 3.5; Autodesk Inc).[18,23] Using an Axiom Dual Extruder 3D Printer (Airwolf 3D,), we produced four 3D models. Two were labelled with organ names for educational purposes, and the remaining 2 were used for examining and evaluating the effects of education. The cost and time required to produce the 3D printed pelvic models were measured. The cost of the material used to create the 3D pelvic model was $15. The time required to print the 3D model was 22 hours, and the printing was automatically performed. The time required to color the 3D model was 1 hour.

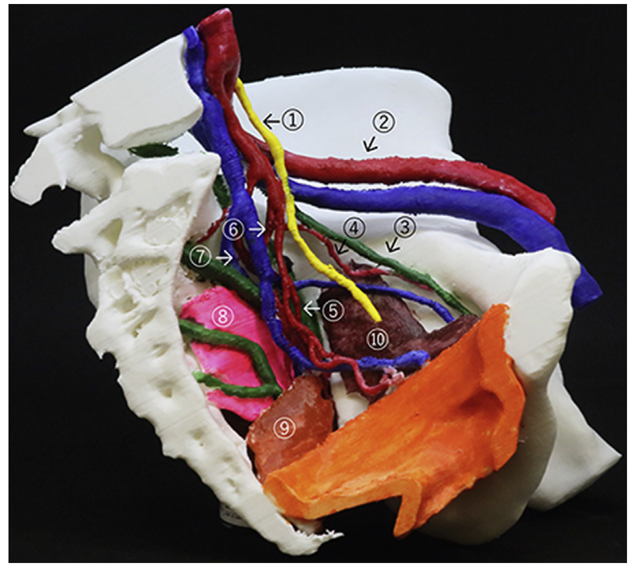

Figure 1. Three-dimensional pelvic models used in this study. (1) Ureter, (2) external iliac artery, (3) obturator nerve, (4) obturator artery, (5) internal pudendal artery, (6) inferior gluteal artery, (7) superior gluteal artery, (8) piriformis muscle, (9) coccygeus muscle, and (10) internal obturator muscle.

Study design and participants

This was a single-center, open-label, randomized, controlled trial comparing a 3D printed model with a textbook as tools to promote anatomic education. From July 2018 to July 2019, a total of 34 medical students, 34 residents (intern during postgraduate years 1 and 2), and 34 young colorectal surgeons (with fewer than 10 years of experience) without LLND experience were enrolled in this study.

A flow chart of this study is shown in Figure 2. Participants were assigned to the 3D pelvic model group or to the textbook group in a block randomized manner, with block sizes of 4. The participants completed a short test

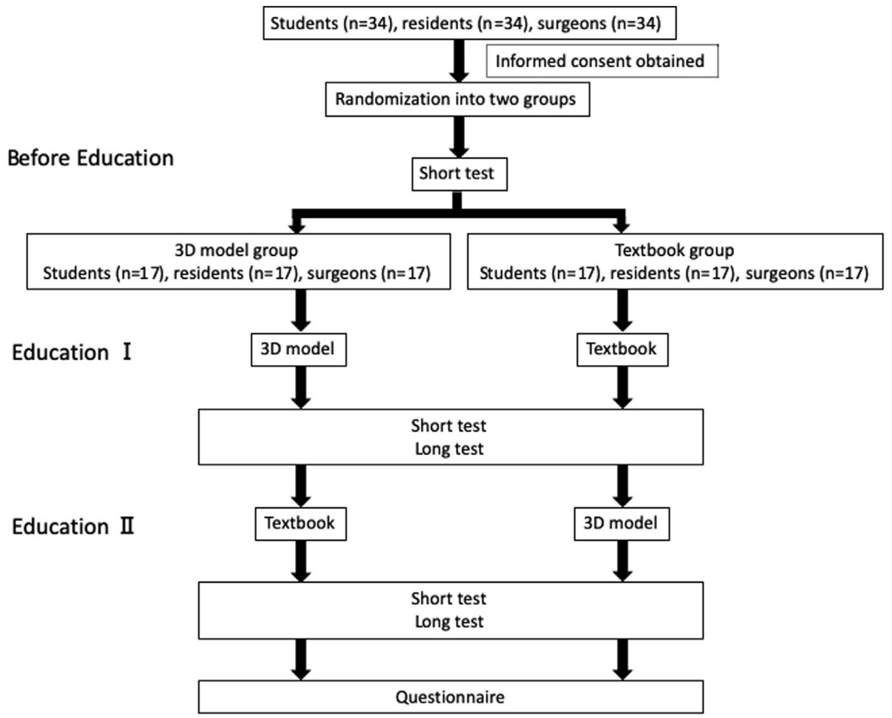

Figure 2. Patient flow chart of the study.

before the educational experiment to confirm their basic knowledge. Participants learned pelvic anatomy using the 3D pelvic model or textbook for 5 minutes (education I); based on the education of the participants, this was sufficient time to study the anatomy. After education I, they completed the same short test again and another long test to evaluate their learning outcomes. After that, they exchanged education tools (education II); the 3D pelvic model group performed self-directed learning with the textbook, and the textbook group performed self-directed learning with the 3D pelvic model so that both groups could learn anatomy with both the textbook and the 3D pelvic model. Then, they completed the same short and long tests again. Finally, we distributed a subjective questionnaire to the participants so they could describe their experience with this type of education.

Contents

Contents of the short and long tests are shown in eFigures 2, 3, and eDocument 1. The short test comprised 10 questions. The long test included 4 sections: questions regarding the names of 10 assigned structures in the textbook (section A), 3D virtual images (section B), the 3D model (section C), and the intraoperative scene (section D). The subjective questionnaire was created based on several previous studies[18,24] and comprised 7 parts regarding satisfaction, enjoyment, learning efficiency, authenticity, attitude, usefulness, and intention to use. Participants answered questions using a 5-point Likert scale (1, strongly disagree; 5, strongly agree).

Endpoints

The long test scores after education I were the primary endpoint. Secondary endpoints were short test scores after education I and long test increment scores between education I and education II.

Statistical analyses

Patients' characteristics were analyzed using the Fischer's method and the *t*-test. Differences in test and questionnaire scores were analyzed using analysis of variance (ANOVA), and the post-hoc Student *t*-test. These analyses were 2-sided, and statistical significance was defined as $p < 0.05$. These statistical calculations were performed using JMP Pro 14.0 for Mac (SAS Institute Inc).

Sample sizes in the groups of students, residents, and surgeons were determined with 1-sided alpha of 0.05, a power of 0.8, the expected score difference was 5 points, and the common standard deviation (SD) of 5 points. The sample size in each group was calculated to be 34 participants.

This study was approved by the Ethics Committees of the University of Tokyo (No. 11872). All participants

Table 1. Participant Characteristics

Characteristic	Three-dimensional model (n = 51)	Textbook (n = 51)	p Value
Student, n = 17			
Sex, n (%)			0.72
Male	10 (59)	12 (71)	
Female	7 (41)	5 (29)	
Short test before education, mean score point (SD)	2.12 (2.28)	2.29 (2.54)	0.83
Resident, n = 17			
Sex, n (%)			1.00
Male	10 (59)	9 (53)	
Female	7 (41)	8 (47)	
Experience as a doctor, y, median (range)	1 (1−2)	1 (1−2)	0.56
Short test before education, mean score point (SD)	2.65 (2.09)	2.35 (1.41)	0.63
Surgeon, n = 17			
Sex, n (%)			0.60
Male	14 (82)	16 (94)	
Female	3 (18)	1 (6)	
Experience as a doctor, y, median (range)	6 (3−10)	6 (3−10)	0.63
Short test before education, mean score point (SD)	4.35 (2.42)	5.35 (1.41)	0.15

provided written informed consent before participating in this study.

RESULTS

Participants

Between July 2018 and July 2019, a total of 102 participants were enrolled in the study. They were randomly assigned as follows: 17 students, 17 residents, and 17 surgeons in the 3D model group, and 17 students, 17 residents, and 17 surgeons in the textbook group. Participant characteristics are shown in Table 1. There was no significant difference between groups regarding characteristics such as sex, professional medical experience, and short test scores before education.

SHORT TEST AND LONG TEST SCORES AFTER COMPLETING THE EDUCATION PROGRAM

Short test and long test scores after completing the education program are shown in Figure 3. Long test scores in the 3D model group after education I were significantly higher than those of the textbook group among students, residents, and surgeons ($p = 0.03$, $p = 0.002$, and $p < 0.001$, respectively), and the mean score of the 3D model group vs textbook group among all participants was 28.9 (95% confidence interval [CI] 27.0 to 30.8) vs 21.7 (95% CI 19.3 to 24.1; $p < 0.001$). Subgroup analysis results are shown in Table 2. After completing section B (3D virtual image section) and section C (3D model section) of the test, the scores of the 3D model group were significantly higher than those of the textbook group. And after completing section D (intraoperative scene section), the scores of the 3D model group were significantly higher than those of the textbook group for residents and surgeons. There was no difference between the 3D model group and textbook group regarding the scores of section A (textbook image section) of the test.

Similarly, the short test scores of the 3D model group after education I were significantly higher than those of the textbook group for students, residents, and surgeons ($p = 0.05$, $p = 0.05$, and $p = 0.009$, respectively). After education II, there was no significant difference in short test scores of the textbook group and 3D model group.

The textbook group (educated using the 3D model after being educated using the textbook) had significantly higher long test increment scores than the 3D model group (educated using the textbook after being educated with the 3D model) after education II. The increment scores of the 3D model group were significantly lower than those of the textbook group for students, residents, and surgeons ($p = 0.009$, $p < 0.001$, and $p < 0.001$, respectively). Finally, after education II, there was no significant difference in long test scores between the textbook group and the 3D model group.

Evaluation of test scores of the 3D model group

In the 3D model group, the short test scores of students (mean 2.12; 95% CI 1.01 to 3.23) and residents (mean 2.65; 95% CI 1.54 to 3.75) before education were significantly lower than those of surgeons (mean 4.35; 95% CI 3.25 to 5.46 surgeon vs student: $p = 0.006$; surgeon vs resident: $p = 0.03$). After education using the 3D model, the short test scores of students (mean 7.65; 95% CI 6.99 to 8.42) were significantly lower than those of surgeons ($p = 0.01$; mean 9.12; 95% CI 8.34 to 9.89). However, the short test scores of residents (mean 8.47; 95% CI 7.80 to 9.14) were not significantly different from those of surgeons. Similarly, after education II, the scores of students

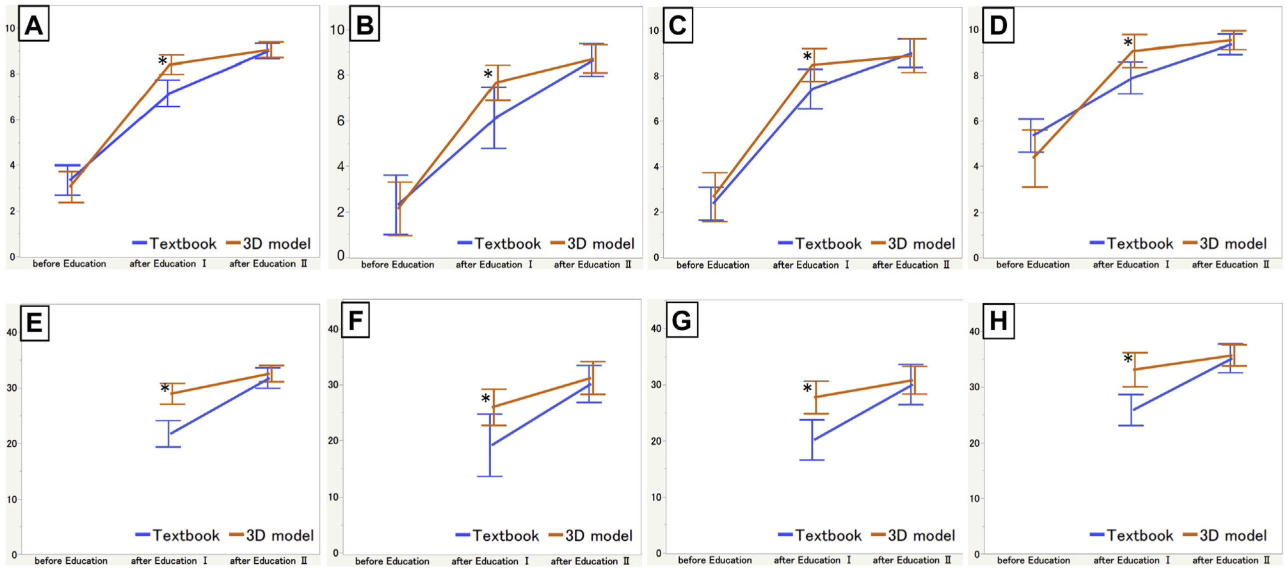

Figure 3. Scores of the short and long tests. The scores of the short tests are shown for (A) all participants, (B) students, (C) residents, and (D) surgeons. Similarly, the scores of the long tests are shown for (E) all participants, (F) students, (G) residents, and (H) surgeons. The scores of the 3-dimensional (3D) model group after Education I was significantly higher than those of the textbook group for students, residents, and surgeons. *$p < 0.05$.

in the 3D model group tended to be lower than those of surgeons ($p = 0.03$).

Questionnaire

The results of the questionnaire are shown in Table 3. Completed questionnaires indicated that the positive feedback rate (4, agree; 5, strongly agree) exceeded 60%. The rate of positive feedback was lower for students than for residents and surgeons. In particular, the attitude question (3D model is the best material in anatomic education) scores indicated by students were significantly lower than those indicated by residents ($p = 0.01$) and surgeons ($p = 0.007$). Furthermore, scores for the questions on anatomic enjoyment ("3D model aroused my interests in anatomy") and usefulness ("3D model is useful for anatomy education") indicated by students were significantly lower than those indicated by surgeons (enjoyment; $p = 0.003$) (usefulness; $p = 0.03$).

DISCUSSION

In this study, pelvic anatomy education was more effective with the 3D pelvic model than with the textbook for students, residents, and young surgeons. Some randomized, controlled trials have indicated the effectiveness of educating medical students using 3D models of the heart,[17] skull,[18] and spine.[19] In this study, the 3D model was also a useful tool for acquiring anatomic knowledge required for LLND. Moreover, we demonstrated the effectiveness of the 3D model for educating not only students, but also residents and young surgeons. According to the sub-analysis of the long test scores after education I, the 3D printed model more effectively resulted in positive scores for test section D (intraoperative scene section). Comprehension of the intraoperative scene improved after education by using 3D pelvic model. Results of the questionnaire reflected the degree of satisfaction with the 3D pelvic model used for educational purposes. The majority of participants agreed with the utility of 3D pelvic education.

Among the 3D model group, the test scores of residents before education were worse than those of surgeons. However, for residents and surgeons, the scores after education I and the final scores were similar. Because it is easy to comprehend spatial relationships using 3D models, they could be good educational tools regardless of the knowledge already possessed by students, residents, and surgeons.

This study also established the low cost of mass productivity of 3D models. The cost for materials was only \$15. Compared with other organ models (\$14 to create a skull model[18] and \$20 to create a fractured spine model[19]), it is feasible and inexpensive to distribute 3D pelvic models to all students for 1 lesson.

Table 2. Test Results after Education

Group, test result	3D model group, mean (SD)	Textbook group, mean (SD)	p Value
Student			
Education I, point			
Long test score total*	25.9 (6.28)	19.2 (10.8)	0.03†
Section A (textbook)	7.24 (2.28)	6.41 (3.04)	0.38
Section B (3D image)	8.06 (2.08)	5.53 (3.34)	0.01†
Section C (3D model)	7.82 (2.04)	5.47 (2.94)	0.01†
Section D (operative scene)	2.82 (1.29)	1.76 (2.39)	0.12
Short test score	7.65 (1.50)	6.12 (2.60)	0.05†
Education II, point			
Long test score total	31.2 (5.71)	30.1 (6.41)	0.61
Education II-Education I‡, point	5.24 (4.54)	10.9 (6.99)	0.009†
Resident			
EducationI, point	27.7 (5.64)	20.1 (6.96)	0.002†
Long test score total*	7.12 (2.34)	6.88 (2.12)	0.76
Section A (textbook)	8.29 (1.76)	5.53 (2.58)	0.001†
Section B (3D image)	8.47 (1.59)	5.41 (2.24)	<0.001†
Section C (3D model)	3.82 (2.07)	2.29 (1.36)	0.02†
Section D (operative scene)	8.47 (1.42)	7.41 (1.70)	0.05†
Short test score			
Education II, point	30.8 (4.76)	30.0 (6.97)	0.71
Total score, point	3.06 (4.05)	9.88 (5.01)	<0.001†
Education II-Education I‡, point	27.7 (5.64)	20.1 (6.96)	0.002†
Surgeon			
Education I, point	33.1 (5.93)	25.8 (5.40)	<0.001†
Long test score total*	8.18 (2.35)	8.06 (1.43)	0.86
Section A (textbook)	8.88 (1.41)	6.82 (1.55)	<0.001†
Section B (3D image)	9.35 (0.93)	6.76 (1.79)	<0.001†
Section C (3D model)	6.65 (2.29)	4.18 (2.16)	0.003†
Section D (operative scene)	9.12 (1.22)	7.88 (1.37)	0.009†
Short test score			
Education II, point	35.6 (3.67)	35.1 (5.05)	0.73
Total score	2.59 (3.10)	9.29 (5.44)	<0.001†
Education II-Education I‡, point	33.1 (5.93)	25.8 (5.40)	<0.001†

*Sections A, B, C, and D were examinations regarding the names of 10 assigned structures in the textbook, 3D virtual images, the 3D model, and the intraoperative scene.
†Significant.
‡Increment point, which is the score obtained from the total score after Education I is subtracted from the total score after Education II.
3D, 3-dimensional.

There were some limitations to this study. First, the number of participants was small. Experiments involving more participants might lead to more definite conclusions. Second, the surgeons participating in this study were limited to colorectal surgeons without experience in performing LLND. Third, we demonstrated only the usefulness of the 3D pelvic model for understanding the intraoperative findings in this study. It is unknown how effective or helpful the 3D pelvic model would be for improvement of the procedure of LLND during real surgery. However, the 3D pelvic model has a potential for less blood loss and shorter surgical time due to acquiring the image of the branching of the vessels and the position of the metastasized lymph nodes. It is necessary to evaluate the effectiveness of the 3D pelvic model as a navigation tool.

CONCLUSIONS

In this randomized, controlled trial, both the objective assessments and subjective questionnaire indicated that the 3D pelvic model was more useful for educational purposes than the textbook.

Table 3. Questionnaire Results

	Likert scale response						
Question, group	1-strongly disagree	2-disagree	3-neutral	4-agree	5-strongly agree	Mean (SD)	p Value
Satisfaction, n (%)							0.38
Student	0 (0)	1 (3)	5 (15)	11 (32)	17 (50)	4.29 (0.84)	
Resident	0 (0)	1 (3)	4 (4)	12 (35)	17 (50)	4.32 (0.81)	
Surgeon	0 (0)	0 (0)	2 (6)	12 (35)	20 (59)	4.53 (0.61)	
Enjoyment, n (%)							0.008*
Student	0 (0)	3 (9)	6 (18)	14 (42)	11 (32)	3.97 (0.94)	
Resident	0 (0)	1 (3)	5 (15)	18 (53)	10 (29)	4.09 (0.75)	
Surgeon	0 (0)	0 (0)	1 (3)	14 (42)	19 (56)	4.52 (0.56)	
Efficiency, n (%)							0.43
Student	0 (0)	1 (3)	0 (0)	13 (38)	20 (59)	4.53 (0.66)	
Resident	0 (0)	0 (0)	1 (3)	12 (35)	21 (62)	4.59 (0.56)	
Surgeon	0 (0)	0 (0)	0 (0)	10 (29)	24 (71)	4.71 (0.46)	
Authenticity, n (%)							0.09
Student	0 (0)	2 (6)	9 (26)	13 (38)	10 (29)	3.91 (0.90)	
Resident	0 (0)	0 (0)	2 (6)	20 (59)	12 (35)	4.29 (0.58)	
Surgeon	0 (0)	0 (0)	5 (15)	18 (53)	11 (32)	4.18 (0.67)	
Attitude, n (%)							0.007*
Student	1 (3)	3 (9)	11 (32)	12 (35)	7 (21)	3.62 (1.02)	
Resident	0 (0)	1 (3)	5 (15)	17 (50)	11 (32)	4.11 (0.77)	
Surgeon	0 (0)	0 (0)	3 (9)	21 (62)	10 (29)	4.21 (0.59)	
Usefulness, n (%)							0.03*
Student	0 (0)	1 (3)	4 (12)	16 (47)	13 (38)	4.21 (0.77)	
Resident	0 (0)	0 (0)	2 (6)	13 (38)	19 (56)	4.50 (0.62)	
Surgeon	0 (0)	0 (0)	1 (3)	11 (32)	22 (65)	4.62 (0.55)	
Intention, n (%)							0.29
Student	0 (0)	2 (6)	5 (15)	11 (32)	16 (47)	4.21 (0.91)	
Resident	0 (0)	0 (0)	2 (6)	12 (35)	20 (59)	4.53 (0.61)	
Surgeon	0 (0)	0 (0)	1 (3)	14 (42)	19 (56)	4.53 (0.56)	

*Post-hoc $p < 0.05$.

Author Contributions

Study conception and design: Murono, Nozawa, Hata
Acquisition of data: Hojo
Analysis and interpretation of data: Oba
Drafting of manuscript: Hojo
Critical revision: Kawai, Tanaka, Ishihara

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eDocument 1.

SHORT TEST. THE SHORT TEST WAS COMPRISED OF 10 QUESTIONS.

List 5 branches of the internal iliac arteries which you know of: (1), (2), (3), (4), (5).

The (6) nerve is the largest nerve of the body and is derived from spinal nerves L4 to S3.

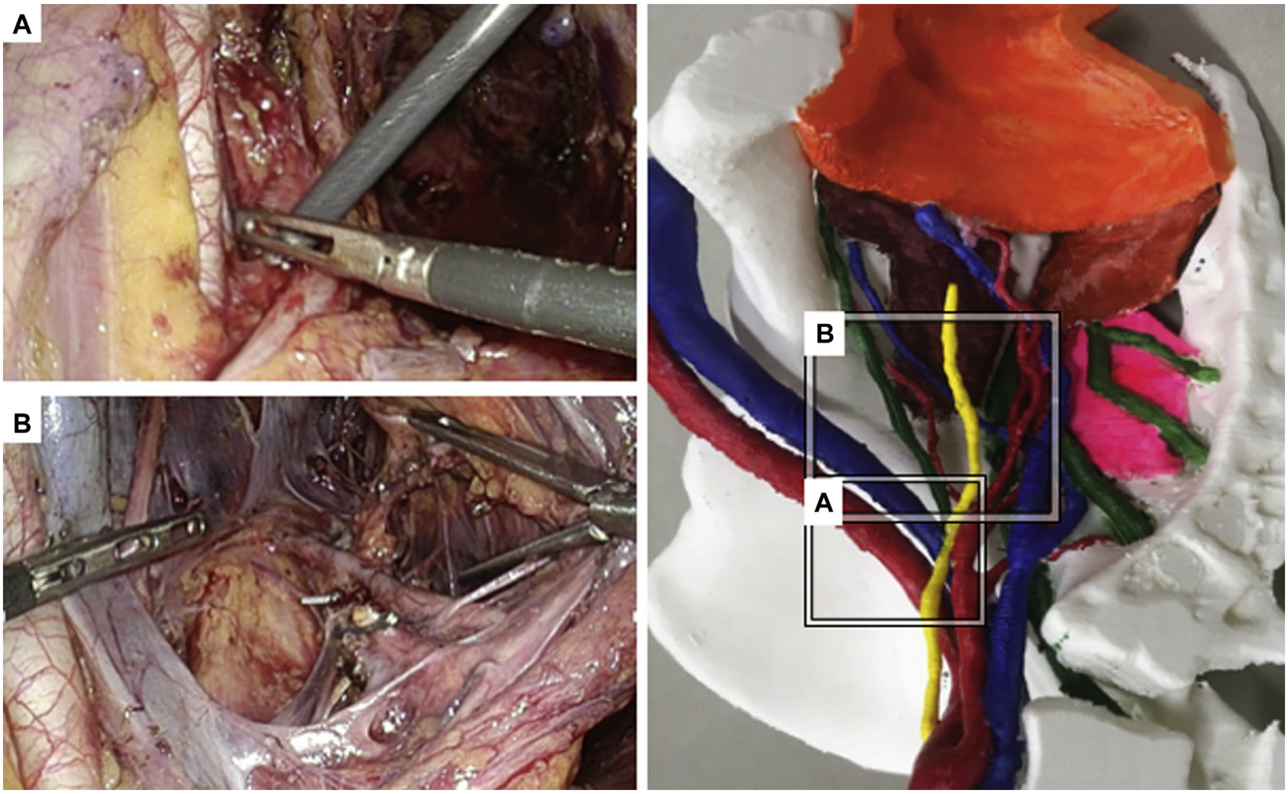
The (7) nerve arises from the anterior rami of nerves L2 to L4, descends in the psoas major muscle, continues posterior to common iliac vessels, and enters the obturator canal.

The (8) muscle originates in the bridges of the bone between the 4 anterior sacral foramina. It passes laterally through the greater sciatic foramen, crosses the posterosuperior aspect of the hip joint, and inserts into the greater trochanter of the femur.

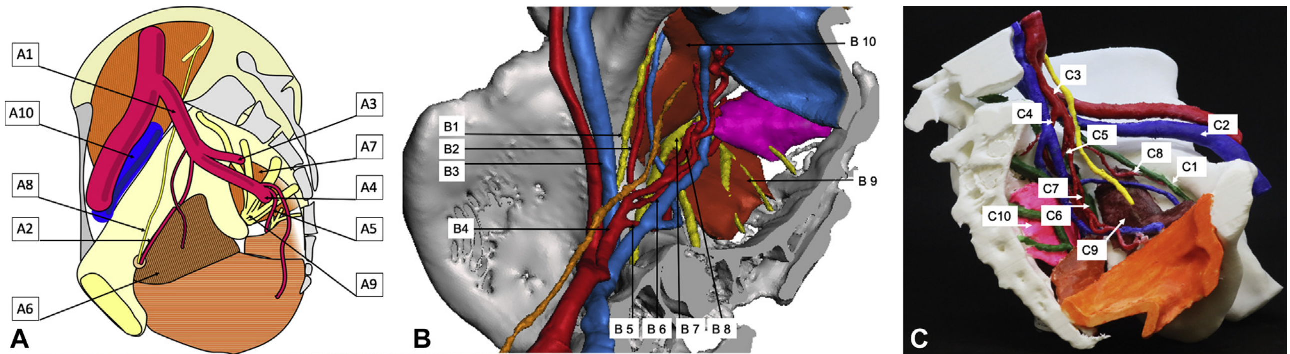
The (9) muscle originates from the deep surface of the obturator membrane and from associated origins of the pelvic bone that surround the obturator foramen. The muscle fibers converge to form a tendon that leaves the pelvic cavity through the lesser sciatic foramen and insert on the greater trochanter of the femur.

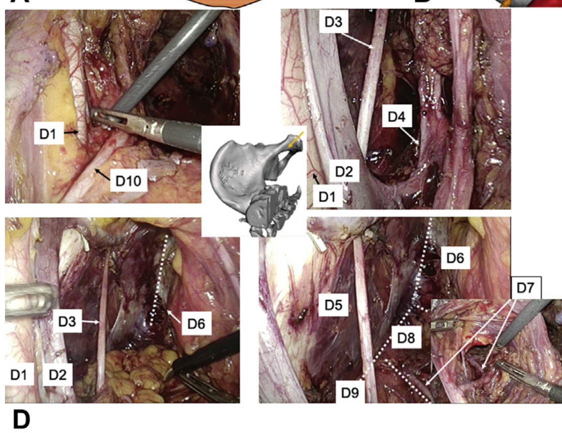
The (10) muscle originates from the apex of the sacrum and inserts into the coccygeal bone and supports the posterior aspect of the pelvic bone.

1	( ) artery	6	( ) nerve
2	( ) artery	7	( ) nerve
3	( ) artery	8	( ) muscle
4	( ) artery	9	( ) muscle
5	( ) artery	10	( ) muscle



eFigure 1. Lateral lymph node dissection using the 3-dimensional pelvic model.





E

A1	( ) artery	A6	( ) muscle	C1	( ) nerve	C6	( ) nerve
A2	( ) artery	A7	( ) muscle	C2	( ) vein	C7	( ) artery
A3	( ) artery	A8	( ) nerve	C3	( ) artery	C8	( ) artery
A4	( ) artery	A9	( ) nerve	C4	( ) artery	C9	( ) muscle
A5	( ) artery	A10	( ) vein	C5	( ) artery	C10	( ) muscle

B1	( ) nerve	B6	( ) artery	D1	( ) artery	D6	( ) muscle
B2	( ) artery	B7	( ) nerve	D2	( ) vein	D7	( ) artery
B3	( ) vein	B8	( ) artery	D3	( ) nerve	D8	( ) muscle
B4	( ) artery	B9	( ) muscle	D4	( ) artery	D9	( ) muscle
B5	( ) artery	B10	( ) muscle	D5	( ) muscle	D10	( )

eFigure 2. Long test. (A) The long test included 4 sections: questions regarding the names of 10 assigned structures in the textbook, (B) 3-dimensional (3D) virtual images, (C) the 3D model (section C), and (D) the intraoperative scene. (E) The long test comprised 40 questions.

Satisfaction	I was satisfied with studying the pelvic anatomy with the 3D model.
Enjoyment	3D model aroused my interests in anatomy.
Efficiency	3D model aided in spatial comprehension.
Authenticity	3D model presents authentic and integral pelvic features.
Attitude	3D model is the best material in anatomical education.
Usefulness	3D model is useful for anatomy education.
Intention	I'm glad to participate in more education with the 3D model.

eFigure 3. Questionnaire for the 3-dimensional (3D) pelvic model. The subjective questionnaire was composed of 7 parts regarding satisfaction, enjoyment, learning efficiency, authenticity, attitude, usefulness, and intention to use. Participants answered questions using a 5-point Likert-scale (1, strongly disagree; 5, strongly agree).

eTable 1. International Committee of Medical Journal Editors Data Sharing Statement

Question	Answer
Will individual deidentified participant data (including data dictionaries) will be shared?	No, no data will be shared.
What data in particular will be shared?	No data will be shared.
Will additional related documents be available (eg study protocol, statistical analysis plan)?	No additional documents will be available.
When the data will become available and for how long?	No data will be shared.
Who will have access to the data?	No one access the data.
For what types of analyses will the data be available?	No data will be available.
By what mechanism will the data become available?	No data will be available.