REVIEW

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CLINICAL ENDOSCOPY

Simulator-based training method in gastrointestinal endoscopy training and currently available simulators

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The apprenticeship-based training method (ABTM) is highly effective for gastrointestinal (GI) endoscopic training. However, the conventional ABTM has significant issues. Although many supplementary training methods (TMs) have been developed and utilized, they cannot entirely replace the ABTM, which remains the major TM strategy. Currently, new TM construction is crucial and necessary due to financial constraints, difficulty of obtaining sufficient training time due to patient safety-related regulations, and catastrophic damage caused by disasters such as the coronavirus disease 2019 pandemic. The simulator-based TM (SBTM) is widely accepted as an alternative to the ABTM, owing to the SBTM's advantages. Since the 1960s, many GI endoscopy training simulators have been developed and numerous studies have been published on their effectiveness. While previous studies have focused on the simulator's validity, this review focused on the accessibility of simulators that were introduced by the end of 2021. Although the current SBTM is effective in GI endoscopic education, extensive improvements are needed to replace the ABTM. Incorporating simulator-incorporated TMs into an improved ABTM is an attempt to overcome the incompleteness of the current SBTM. Until a new simulator is developed to replace the ABTM, it is desirable to operate a simulator-integrated and well-coordinated TM that is suitable for each country and institution.

Keywords: Apprenticeship-based training method; Colonoscopy; Endoscopic retrograde cholangiopancreatography; Esophagogastroduodenoscopy; Simulator-based training method

INTRODUCTION

Gastrointestinal (GI) endoscopy is a complex procedure that requires simultaneous coordination of technical skills for endoscope manipulation, cognitive skills such as knowledge and lesion diagnosis, and integrative skills such as communication and teamwork. Owing to these factors, it is difficult to effectively train each apprentice according to the trainee's varied knowledge base, baseline dexterity, and learning style.[1-6]

The apprenticeship-based training method (ABTM) is highly beneficial for endoscopic training and remains the cornerstone of the GI endoscopy training method (TM). However, owing to the numerous significant flaws of the conventional ABTM, considerable efforts for improvement have been introduced. Incorporating simulators into GI endoscopy training programs is a major trend in such efforts.

Since the 1960s, multiple GI endoscopy training simulators have been constructed and numerous studies on their validity have been published. Although notable comprehensive reviews focused on the validity of training simulators and systems,[1,6-12] they primarily introduced simulators from an academic perspective. Consequently, applying these recommendations and inferences as guidelines for establishing an endoscopic educa-

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tion program in general education institutions is challenging. Therefore, this review focuses on the accessibility of simulators from a practical standpoint, with particular emphasis on simulators that were introduced by the end of 2021.

The following describes the practical perspective that we outlined: (1) Selection criteria were established based on the accessibility of the simulator. This necessitates access to either the domestic market or the international. (2) From the perspective of a potential client, the simulator selected was one for which estimates of costs and manpower required for installation and maintenance could be made. Considering this, we endeavored to include as many low validity and low cost, moderate validity and moderate cost, and high validity and high cost categories as possible. (3) GI endoscopy competencies that can be learned with training are outlined; however, if no official data were available, then estimates were made based on our experience. (4) Whether an educational program utilizing the simulator had been created and whether there is documented evidence of the simulator's validity was assessed.

Only esophagogastroduodenoscopy (EGD), colonoscopy, and endoscopic retrograde cholangiopancreatography (ERCP) simulators are covered in this article; endoscopic ultrasonography (EUS) and enteroscopy simulators are not covered. Moreover, it should be noted that augmented reality, mixed reality, and extended reality-based simulators, which are technically superior to virtual reality (VR) series, are still in the early stages of development and are difficult to implement in actual endoscopic training. Hence, they were excluded from this study.

THE IMPERATIVE NEED FOR A NEW, EFFECTIVE GI ENDOSCOPY TM

The ABTM is characterized by "See one, Do one, Teach one." In the ABTM, apprentices can directly observe a demonstration by experts, and under the supervision of specialists, it is feasible to train real patients in a step-by-step, real-time manner that advances from low to high difficulty, which is highly beneficial for endoscopic training.[3-5,7,13] However, the conventional ABTM has numerous significant flaws.[1,3-5,8,9,13-17] In the conventional ABTM, the majority of trainers do not receive separate educational training, there is no formal and standardized training curriculum, and there is no formal competency assessment tool. Consequently, the final competency of the trainee is typically determined by training time or volume. When the number of educators and trainees exceeds a certain threshold, the efficiency of education declines significantly. In addition, when the apprentice performs the endoscopy directly on the patient, there is a delay in the examination time, the patient may experience inconvenience until they are accustomed to the technique, and there is a risk of complications. Regarding the content of training, if the trainer does not teach according to the trainee's level, the trainee may perceive the training as too simple or too challenging, resulting in ineffective education. Additionally, if endoscopic takeover occurs frequently because of the patient's medical condition, sufficient education is not provided. Furthermore, a significant amount of time is required to educate a desirable number of cases through actual patients.

Numerous studies have been conducted on the development of a structured curriculum employing competency-based assessment tools and validated direct observation tools[4,5,18-28]; the development and incorporation of milestone concepts[5,21,23]; the development of quality indicators (e.g., adenoma detection rate, cecal intubation rate)[5,21]; the recognition and incorporation of cognitive load theory[5,20]; the incorporation of mastery learning[5,14,29,30]; the development of high-quality, constructive, and effective feedback[5,19-21,29,31]; the incorporation of effective coaching techniques[5]; the development of a training program for endoscopic trainers[4,5,19,20,32]; and the emphasis on a learning environment that supports education.[20] However, there is no new TM that can completely replace the ABTM, and the establishment of a new education system is very expensive and requires the commitment of endoscopic specialists.[4,8] Consequently, despite several concerns, the ABTM has remained the dominant TM to date.

Nonetheless, as hospitals grow and expand, the number of educators and trainees increases, "Teach one" becomes more challenging, and financial demand on endoscopic performance in management continues to rise. Endoscopy educators find it increasingly difficult to secure training time during examinations as the number of patient safety-related medical regulations increases.[20,33]

Furthermore, as a result of the coronavirus disease 2019 pandemic, the number of examinations at endoscopy centers, where GI endoscopy education is mostly delivered, was reduced by up to 99%, resulting in a sudden and severe decrease in the availability of endoscopic education for apprentices.[1,34-44] In the last two years, endoscopists who lacked adequate education have entered the medical field, and there has been a significant additional load on monitoring and education.

As the ABTM was discovered to be extremely susceptible to health, financial, and social crises,[14] the establishment of a new TM to complement the ABTM is not a choice that can be made based on the circumstances of each hospital but rather a necessary and obligatory task that must be planned in advance.

The simulator-based TM (SBTM) allows apprentices to practice certain abilities at their own speed without harming a patient. Depending on the type of simulator, apprentices can also train technical, cognitive, and integrative skills simultaneously, as well as advanced skills, such as polypectomy, hemostasis, and endoscopic dissection. It is also possible to standardize a variety of educational indicators. As an alternative and complement to the ABTM, SBTM is the most anticipated alternative in this regard.[1,10,11,45]

CLASSIFICATION AND CHARACTERISTICS OF ENDOSCOPIC TRAINING SIMULATORS

Currently, three types of endoscopic simulators are available: (1) mechanical simulators, (2) *ex vivo* and *in vivo* animal models, and (3) computer-assisted (e.g., VR) models. Each simulator type has its own benefits and drawbacks, and is best suited for training and assessing specific tasks and levels of learners (Table 1).[4,46-57]

While all simulators have the benefit that apprentices can train specific skills at their own pace without endangering the patient, they are only effective in the initial phase of beginner education, and there is no high-quality evidence that the SBTM can make a clear contribution to competency acquisition.[4,7,8]

Mechanical model

The most commonly used training simulator is the mechanical simulator. In general, the exterior of this simulator is supported by a hard material, such as plastic, whereas the interior consists of a physical model containing a phantom made from a soft material, such as silicone. The cavity within the phantom was created to simulate the physical and visual properties of human anatomical structures, allowing for the insertion of an endoscope and the training of endoscopic maneuvers. This type of simulator has the advantages of being less expensive than other simulators, effective for the initial phase of apprentice training, and superior to VR simulators in terms of physical haptic realism. However, the realism of the mechanical model's physical properties is inferior to that of animal models, and implementation of different scenarios requires physical reproduction such that only fundamental skills and a limited scenario set can be trained using the mechanical model.[1,4,5,7,8]

1) EGD Method Trainer

The EGD Method Trainer (EMT; Anymedi Inc., Seoul, Korea; https://anymedi.com) is a training simulator of the diagnostic EGD maneuver that realistically reproduces the human upper GI tract using three-dimensional (3D) modeling, 3D printing, and silicone molding technology based on a computed tomography (CT) image of the human upper GI tract.[1,48] Training in endoscope manipulation and systemic observation of the upper GI tract are feasible. It is possible to insert and observe up to the second portion of the duodenum because the model is based on an actual CT scan of a human being and uses silicone with the same hardness as that of the human tissue. In addition, a machine learning program comparing the endoscopist's motion analysis matrix to the expert's matrix is provided, such that the trainee can self-train. The use of soft silicone requires an intensive lubrication process and more careful management than that of a conventional mechanical simulator. This product is commercialized; its domestic price is approximately US dollar 4,000-4,500, and the actual training video can be viewed on YouTube (performance video: https://www.youtube.com/watch?v=Rzbshcwe3ZE). By 2021, the only data available to evaluate the validity of this model was a developer's paper demonstrating positive face, content, and construct validity.[48]

2) EGD Simulator

A silicone frame resembling the human body from the nose and mouth to the esophagus, stomach, and duodenum is mounted on a plastic panel, and the entire procedure of upper GI endoscopy, including transoral or transnasal insertion, can be performed on a model. On the inner wall of the gastric model, there is a spot that is shaped like a gastric ulcer or early gastric cancer and a location where Yamada I to IV polyp models can be inserted. Attaching a polyp to perform polypectomy and control bleeding is a separate option. After resection, the clipping method can be used to stop the bleeding. Moreover, the opening of the ampulla of Vater is in the second portion of the duodenum, and when ERCP is used, cannulation can be attempted with the common bile duct and pancreatic duct. In one study that evaluated the educational effect of this simulator by applying it to actual novice and non-novice endoscopists using the previous version of the product currently on the market, 90.6% of participants, particularly 92.9% of novice endoscopists, rated the simulator as helpful, demonstrating its efficacy (EGD Simulator; Koken Co., Ltd., Tokyo, Japan; https://www.kokenmpc.co.jp/english/products/educational_medical_mod-

Table 1. Commercialized gastrointestinal endoscopy training system

Name	Manufacturer (year of release)	Class	Target	Intervention	Efficacy validation	Price (US dollar)
EGD Simulator	Koken Co., Ltd., Japan	Mechanical	EGD, ERCP	Yes	Yes (EGD)[46]	5,476[a)]
EMS Trainer	Chamberlain Group LLC, USA	Mechanical	EGD, CSPY	Yes	No	2,089
Thompson Endoscopic Skill Trainer	EndoSim LLC, USA	Mechanical	EGD, CSPY	Yes	Yes[47]	12,995
Upper GI Trainer	Chamberlain Group, USA	Mechanical	EGD	No	No	3,790
EGD Method Trainer	Anymedi Inc., Korea (2019)	Mechanical	EGD	No	Yes[48]	4,000–4,500[a)]
Erlangen Active Simulator for Interventional Endoscopy Series	EndoSim LLC, USA	*Ex vivo*	EGD, CSPY, ERCP, EUS	Yes	Yes (EGD[49,50], ERCP[51])	2,100–4,295
DeLegge EndoExpert Tray	DeLegge Medical, USA	*Ex vivo*	EGD, CSPY, ERCP	Yes	No	2,250
EndoVR	CAE Healthcare, Canada	VR	EGD, CSPY, ERCP	Yes	Yes (CSPY[52], ERCP[53])	119,600
GI Mentor II virtual endoscopy simulator	Simbionix, USA	VR	EGD, CSPY, ERCP	Yes	Yes (EGD[54], ERCP[55], CSPY[56])	72,000–134,000
EndoSim	Surgical Science, Sweden	VR	EGD, CSPY, ERCP	Yes	No	60,000–132,000
3D Colonoscope Training Simulator NKS	Kyoto Kagaku Co., Japan	Mechanical	CSPY	No	No	1,929[a)]
Colonoscope Training Simulator	Kyoto Kagaku Co., Japan	Mechanical	CSPY	No	Yes[57]	2,450[a)]
Colonoscopy Lower GI Endoscopy Simulator	Koken Co., Ltd., Japan	Mechanical	CSPY, enteroscopy	Yes	No	3,990[a)]
Colonoscopy Trainer	Chamberlain Group, USA	Mechanical	CSPY	No	No	3,630
EVL Simulator	Glück Co., Korea	Mechanical	EVL	Yes	No	950[a)]
PEG Simulator	Glück Co., Korea	Mechanical	PEG	Yes	Yes[58]	1,500[a)]
Left-Hand Trainer	Glück Co., Korea	Mechanical	EGD	No	No	1,200[a)]
EndoGel Training Model for ESD/POEM	Sunarrow Co., Japan	Mechanical	ESD/POEM	Yes	Yes[59]	390[a)]
ESD Training Model	Koken Co., Ltd., Japan	Mechanical	ESD	Yes	No	2,105[a)]

EGD, esophagogastroduodenoscopy; ERCP, endoscopic retrograde cholangiopancreatography; CSPY, colonoscopy; EUS, endoscopic ultrasonography; VR, virtual reality; 3D, three-dimensional; EVL, endoscopic variceal ligation; PEG, percutaneous endoscopic gastrostomy; ESD, endoscopic submucosal dissection; POEM, per-oral endoscopic myotomy.
[a)]Domestic price.

els/anatomical/lm-103.html; introduction video: https://www.youtube.com/watch?v=J1iKCc821Lk).[46]

3) EMS Trainer

In this simulator (EMS Trainer; Chamberlain Group LLC, Great Barrington, MA, USA; https://www.thecgroup.com/product/ems-trainer-2068), silicone models of the stomach, colon, and esophagus are combined into one frame. After each tissue element has been inserted into the model, advanced techniques, such as tissue biopsy, clipping for gastric ulcer bleeding, and stenting for esophageal, pyloric, and duodenal strictures, can be performed. Additionally, the colon frame can be outfitted with tissue elements for practicing snaring of colon polyps, post-polypectomy clipping, colonic perforation clipping, and stent insertion into the colonic stricture. Owing to the nature of the model created by imitating only a partial structure of the whole organ, it is impossible to practice the overall endoscopic manipulation; nevertheless, this simulator is thought to be useful for teaching endoscopy apprentices detailed techniques. However, no clinical studies have demonstrated the effectiveness of this device.

4) Upper GI Trainer and Colonoscopy Trainer

While the EMS Trainer described previously was a simulator that focused on training each detailed technique rather than the endoscopic insertion technique, the Upper GI Trainer and Colonoscopy Trainer (Chamberlain Group LLC; https://www.thecgroup.com/product/upper-gi-trainer-2002) replicate the structure of the human body from the oral cavity to the esophagus, stomach, duodenum, and large intestine for the purpose of endoscopic insertion. Thus, these trainers are believed to be beneficial for apprentices just beginning endoscopy. However, unlike the EMS Trainer, which is manufactured by the same company, there is no component for mounting tissue elements for practicing detailed techniques. Thus, the GI Trainer and Colonoscopy Trainer are expected to be cumbersome to use in conjunction with the EMS Trainer, if required. Additionally, no clinical studies have demonstrated the effectiveness of these devices.

5) Thompson Endoscopic Skill Trainer

This is a simulator designed for preclinical beginners (Thompson Endoscopic Skill Trainer; EndoSim LLC, Hudson, MA, USA; https://endosim.com/product-page/thompson-endoscopic-skills-trainer-test). The simulator is used to practice the five skills of polypectomy, retroflexion, torque, knob control, and loop reduction or navigation. A module with a light bulb attached to a small ring or silicone cap is mounted inside the box. In 2014, the developer validated the simulator with 54 participants. The content validity index of all five modules was found to be close to 1.00 in terms of realism, relevance, and representativeness.[47] This simulator is useful for practicing deconstructed basic skills, similar to the EMS Trainer described above, but the integrated technical skill of endoscopy cannot be practiced.

6) Colonoscope Training Simulator

It is a mechanical model that implements a colon tube with the rectum and 41 folds within a hard case that imitates the abdominal cavity (Colonoscope Training Simulator; Kyoto Kagaku Co., Kyoto, Japan; https://www.kyotokagaku.com/en/products_data/m40/; introduction video: https://www.youtube.com/watch?v=XDbRA3I-2Hc). There are numerous devices that can fix the colon-rectum tube of the abdominal cavity, giving this model the benefit of being able to implement complex insertion difficulties in comparison to the 3D Colonoscope Training Simulator NKS (Kyoto Kagaku Co.). In addition, external compression and position change are possible, and the pump attached to the anus allows for adjustment of the anal sphincter's power. The product weighs approximately 6.5 kg, making it relatively easy to transport, and its catalog is available online. As a colonoscopy-specific simulator, a 2016 clinical study involving 32 endoscopic apprentices showed that the trained group had a higher rate of cecal intubation than the untrained group.[57]

7) 3D Colonoscope Training Simulator NKS

It is a mechanical model that implements the 3D structure of the large intestine based on the CT colonoscopy data (3D Colonoscope Training Simulator NKS; https://www.kyotokagaku.com/en/products_data/mw24/; introduction video: https://www.youtube.com/watch?v=Rhhi-yRazl4). Inside the transparent tube is a silicone implementation of the large intestine, which allows visual inspection from the outside of various loops that can occur when inserting the endoscope. In a simulator designed specifically for cecal intubation, a short- or long alpha loop and N-loop can be artificially set in the tortuous colon to aid in loop reduction during endoscopic insertion. In addition, this simulator weighs 6 kg, making it transportable. It is possible to use the simulator for implementation of abdominal compression and positional changes externally.

However, it cannot be used to observe other lesions or for therapeutic endoscopic training, and there are currently no clinical studies evaluating the effectiveness of this product.

8) Colonoscopy Lower GI Endoscopy Simulator Type II

It consists of a main unit that creates an abdominal cavity and a colon tube made of special silicone, with the colon tube containing the ascending, transverse, descending, and rectosigmoid sections (Colonoscopy Lower GI Endoscopy Simulator Type II; Koken Co., Ltd.; https://www.kokenmpc.co.jp/english/products/educational_medical_models/anatomical/lm-107.html). Three connectors connect the four colon tubes, and a virtual peritoneal membrane can cover the main unit. Moreover, the main unit can be secured by connecting the hole and fixing the pin to the main unit, and changing the position is possible. This product can be used to perform polypectomy by attaching a simulated polyp, in addition to being used to train basic skills such as cecal intubation. The use of the clipping technique allows for the practice of hemostasis and is another advantage of this simulator. Attaching the optional small bowel makes it possible to use a shortening technique during balloon enteroscopy. You can easily access catalogs and manuals for this device via the internet and learn how to use it via YouTube (introduction video: https://www.youtube.com/watch?v=bKUnhVnwNI4).

9) Endoscopic Variceal Ligation Simulator

This simulator was designed to make it easier for apprentice endoscopists to practice the fundamentals of endoscopic variceal ligation (EVL) during their initial training (Glück Co., Seoul, Korea; https://www.glucklab.com/; performance video: https://www.youtube.com/watch?v=kF57_yyUoAM). EVL can be performed by inserting a varix module into a plastic esophageal-shaped frame. Each varix module is made of silicone and contains three strands of varix per module. Therefore, EVL can be practiced multiple times with a single module, and the practice can be repeated while the varix module is replaced. The band ligator required to perform EVL is not included and must be prepared separately.

10) Percutaneous Endoscopic Gastrostomy Simulator

This simulator allows for the practice of percutaneous endoscopic gastrostomy (PEG; Glück Co.; performance video: https://www.youtube.com/watch?v=F24hX8eoq74) through the abdominal and gastric walls by inserting a silicone module shaped like the abdominal and gastric walls into the hole of a plastic model of the stomach. It is possible to train with different types of PEG, such as pulled and introducer types. It is also helpful that the abdominal and gastric wall silicone modules can be reused multiple times and replaced if needed. In a study to determine the efficacy of the simulator, practice with PEG simulator decreased PEG completion time and increased self-evaluation scores in both pull type and introducer type simulator, indicating that PEG simulator can be useful for educating novice endoscopists in PEG insertion.[58]

11) Left-Hand Trainer

In advanced endoscopy techniques, such as therapeutic endoscopy, the right hand usually manipulates the therapeutic accessory. If the endoscope cannot be manipulated with the left hand alone and the operator must operate the therapeutic accessory with the right hand, an additional assistant is required to maintain the specific position of the endoscope. Thus, the ability to move the bending section upward and downward and rotate the insertion tube using only the left hand is crucial. This simulator is a training simulator for the development of left-hand manipulation skills (Left-Hand Trainer: Glück Co.; performance video: https://www.youtube.com/watch?v=_B0RnR-QJ64). It is more useful for endoscopists who are already familiar with fundamental endoscopic manipulations than for beginners.

12) EndoGel Training Model for endoscopic submucosal dissection/per-oral endoscopic myotomy

A stainless-steel container containing stacked, multilayer, polyvinyl, alcohol, hydrogel plates embodying the physical properties of each wall of the GI tract enables trainees to perform endoscopic submucosal dissection (ESD) or per-oral endoscopic myotomy (POEM) procedures. On the gel plate, mucosal marking, submucosal injection, and submucosal dissection can be performed in the same manner as in actual ESD or POEM procedures. This is thought to be beneficial for advanced endoscopists who practice ESD (EndoGel Training Model for ESD/POEM; Sunarrow Co., Ltd., Tokyo, Japan; https://www.sunarrow.co.jp/medical/en/products/endogel/). In one study, 28 residents practiced ESD and POEM with EndoGel and then completed self-report questionnaire. The satisfaction rate was 100%, and the feasibility rate was 96.4%, indicating that EndoGel may be an effective endoscopy education tool.[59]

13) ESD Training Model

Koken Co., Ltd. created a simulator for ESD training (https://www.kokenmpc.co.jp/english/products/educational_medical_models/anatomical/lm-083.html). It is a model shaped from the distal esophagus to the stomach with a soft resin interior. ESD training can be performed with realistic sensation by inserting a dissected pig stomach into the device. However, the porcine stomach module to be mounted must be prepared and installed separately.

Animal model

The animal model has the highest degree of realism and can simulate specific dynamic conditions, such as bleeding, and the electrosurgical unit can be used because it employs animal organs that are anatomically and haptically similar to those of the human body. This model is more suitable for training advanced therapeutic procedures, such as hemostasis, polypectomy, and ESD, than for training basic techniques. Conversely, the training or reuse of different scenarios in the same simulator is not possible, and the standardization of various competency matrices is difficult. During apprentice training, it is essential to remember that the anatomy and physical characteristics of animals are distinct from those of humans. Pigs are the predominant species in this animal model.[1,4,7]

1) *Ex vivo* animal models

In the *ex vivo* animal model, an organ is attached to a plastic mold and used. The *ex vivo* animal model is less expensive than a VR simulator or an *in vivo* animal model, and because it employs animal tissue, its visual and haptic realities are superior to those of a mechanical simulator. Additionally, this model can be used to train in advanced therapeutic procedures, such as hemostasis and ESD. However, because a devitalized organ is used, its tissue characteristics are inferior to those of the vital organs. This makes the therapeutic procedure difficult or impossible to perform.[1,4,5,8,18]

(1) Erlangen Active Simulator for Interventional Endoscopy

Erlangen has been developing a series of *ex vivo* simulators since 1997. Currently, Erlangen Active Simulator for Interventional Endoscopy (EASIE)-R1, R2, R3, and R4 (EndoSim LLC, Berlin, Germany; https://endosim.com/) have been released.[60] The EASIE-R3 series is a product designed specifically for polishing upper GI endoscopic procedures. Endoscopic mucosal resection (EMR), ESD, POEM, and EUS can be performed by loading the simulator with *ex vivo* porcine GI organ packages suitable for the procedure being practiced. In contrast to live animal models, which are difficult to implement in a general environment, and expensive VR simulators, only the simulator body and *ex vivo* porcine packages are purchased for EASIE, allowing for more realistic training than that of mechanical models and at a lower cost. Furthermore, when using the PEG simulator version, PEG insertion can be performed by replacing the existing EASIE acrylic lid with a lid attached to the porcine abdominal wall. The *ex vivo* porcine package can be purchased again and used multiple times, which is convenient. Tissue disposal after training and the need to accept unfavorable tissue characteristics, unlike the characteristics of vital tissues, are disadvantages of this simulator.

In a 2012 study utilizing CompactEASIE, which was developed in 1998 as the predecessor to the EASIE-R series, 28 novice endoscopists were divided into three groups: those who received both simulator and clinical training, those who received only clinical training, and those who received only simulator training. Changes in the endoscopic technique were subsequently compared. The intubation times for the esophagus and pylorus were significantly shorter in the group that had both simulator and clinical training, and blind expert evaluations were better.[49,50] Furthermore, in a study published in 2005, hemostatic practice using CompactEASIE was performed on 28 GI trainees. Between the baseline and 7 months of training, the trainees' manual skills and clinical hemostatic procedures improved, demonstrating the efficacy of the simulator.[49]

ColoEASIE-2 realistically implements human anatomy using actual cattle or pig intestines. It is possible to learn fundamental techniques, such as cecal intubation; however, owing to the *ex vivo* characteristics, ColoEASIE-2 is more effective for learning interventional procedures, such as EMR or ESD, using human tissue-like models. A separate specimen must be purchased for bleeding or polypectomy. In the case of a bleeding specimen, five to six bleeding vessels are sutured to the specimen to implement various hemostasis techniques. It is difficult to implement various loops that can be encountered during the insertion of an endoscope, and auxiliary methods that can be implemented during insertion, such as abdominal compression and postural change, cannot be implemented. Therefore, the applicability of the simulator is limited to interventional procedures.

The most recent EASIE-R4 simulator is a hybrid simulator that consists of a disposable *ex vivo* specimen (software) in a plastic container (hardware). It contains a torso-shaped tray with attachment clamps to secure the specimen in place. The ERCP module simulates fluoroscopy without the use of X-rays. Using this simulator, trainees can practice cannulation, needle-knife sphincterotomy, stone extraction with a basket, insertion of a biliary stent, EUS-guided biliary access, and cholangioscopy. The ERCP NeoPapilla cartridge is a hybrid cartridge installed and used in the EndoSim EASIE ERCP simulator. It is composed of a porcine *ex vivo* duodenum and an artificial major papilla made of chicken heart tissue. Each specimen cartridge contains 15 to 20 chicken heart papillae. The artificial papilla allows for cannulation of the common bile and pancreatic ducts. Multiple sphincterotomies can be performed on a single specimen by exchanging chicken heart papillae sections without difficulty. The only study that demonstrated the validity of the EASIE-R4 was a recently published abstract in European Society of Gastrointestinal Endoscopy Days 2021. Thirteen participants rated this model as more realistic in terms of organ appearance, endoscopic navigation, and papillary cannulation.[51]

(2) DeLegge EndoExpert Tray

This simulator was created to practice EGD, colonoscopy, and ERCP by mounting *ex vivo* organs within a plastic simulation tray, which is similar to the EASIE series (DeLegge EndoExpert Tray: DeLegge Medical LLC, Awendaw, SC, USA; https://www.organsbydesign.com/collections/all).

2) *In vivo* animal model

This *in vivo* animal model for endoscopic training involves live sedated animals. It has been reported that a simulator involves animals, such as canines[61] and baboons,[62] although the pig model (*Sus scrofa*) is the most common.[63] For training, it is advised to use pigs weighing over 30 kg, as they are the most equivalent to humans.[64] Training with an *in vivo* pig model must be approved by the animal care and use committee of each institute. To cleanse the contents remaining in the stomach and colon of pigs, proper bowel preparation with a clear fluid diet and bowel preparation solution, as well as artificial elimination of food contents, should be performed.[64,65] The anatomy of pigs resembles that of humans, but there are notable differences, such as the presence of a strong and protruding diverticulum on the gastric cardia (so-called torus pyloricus) and a large amount of submucosal fat in the colonic wall, as well as the lack of abdominal fixation of the proximal colon.[64,66] However, this model is the most realistic because its haptic feedback is comparable to that of humans and includes secretions, respiratory movements, and bleeding upon intervention. Therefore, it is commonly used for training advanced therapeutic methods, such as hemostasis and ESD, particularly following *ex vivo* training. However, the model's accessibility is limited. Animal acquisition, raising, monitoring, post-procedure rearing, and euthanasia incur substantial costs. Animals must be administered general anesthesia during endoscopic training. In this process, a veterinarian must be available and a suitable infrastructure for animal breeding and experimentation is required. In addition, ethical controversies surrounding animal research are viewed as a barrier that makes it difficult to implement *in vivo* models.[1,3,5,8,18]

A computer-assisted (VR) model

The VR model constructs VR using a sensor and computer capable of providing haptic, audio, and visual feedback in response to the learner's movement. Once the learner inserts the scope into the machine, the monitor displays the virtual lumen that responds to the learner's motion in real time. Technical skills; cognitive skills, such as managing patient discomfort or adverse events; integrated skills, such as problem solving and decision-making; and even therapeutic procedures can be trained in this process. In addition, unlike other types of simulator models, multiple scenarios can be trained in a single simulator, and unlike animal models, the same scenario can be trained repeatedly. Effective feedback can be provided following training because the model provides objective matrices for measuring trainees' competency. It is possible to standardize the TM because the same scenario can be presented to all trainees multiple times, and the object measurement matrices are calculated each time. Despite its high cost, the effect of the computer-assisted model is limited to the early stages of training. Moreover, the number of scenarios that can be trained is limited, maintenance is difficult, and the haptic and visual realities are inferior to those of the animal model.[4,5,8,11,67]

1) EndoVR

Previously released as an AccuTouch Endoscopy Simulator, the CAE Healthcare VR simulator is a device designed to train polypectomy, biopsy, and hemostasis skills through EGD, colonoscopy, and ERCP modules. When the simulator begins, the virtual patient's medical history is displayed, and vital parameters, such as the virtual patient's electrocardiogram, blood pressure, and oxygen saturation, change in real time during endoscopy, allowing the trainee to practice endoscopy with a sense of realism. The feedback report on the results of the previous endoscopy can be reviewed in detail at the conclusion of the practice, which is believed to be of great assistance in enhancing the skills of apprentice endoscopists. The ERCP module provides endoscopy and fluoroscopy images. It consists of six ERCP modules, all of which are diagnostic; therapeutic procedures, such as sphincterotomy and stenting, are not possible. As with the GI Mentor II, it is anticipated that the number of institutions and facilities with expensive simulators will be restricted.

In a clinical study, trainees who had no prior experience with colonoscopy were randomly assigned to either an educated or a non-educated (control) group. Using the previous model, the Accutouch simulator, the educated group demonstrated a significantly higher rate of cecal intubation within 10 minutes than the control group.[52] In the ERCP validation study, six apprentice GI fellows and four GI faculty members with experience in ERCP performed four simulated cases. The total procedure time, which was the primary outcome, was significantly shorter for the experts than for the novices.[53] However, the validity of this simulator in EGD has never been demonstrated (EndoVR; CAE Healthcare, Montreal, Quebec, Canada; https://www.caehealthcare.com/media/files/User_Guides/EndoVR-User-Guide.pdf).

2) GI Mentor II virtual endoscopy simulator

It is an upper and lower GI endoscopic simulator developed in the United States by Simbionix and offers a module library with over 120 tasks and virtual patient cases (GI Mentor II virtual endoscopy simulator; Simbionix, Cleveland, OH, USA; https://simbionix.com/simulators/gi-mentor/). The simulator has an oral orifice for inserting the endoscope into the torso of the mannequin, which is in a left lateral decubitus position, and a system that feeds back the force applied when manipulating the endoscope. When the operator manipulates the endoscope, related stimuli are displayed on the computer screen, and visual and audible feedback (e.g., the patient's pain simulation) is generated based on the torque, deflation of the dial, and pressure of the endoscope. In addition to cecal intubation, trainees can undergo flexible sigmoidoscopy, bleeding control, and endoscopic procedures, such as EMR or ESD. As with other VR models, this model provides immediate feedback, such as confirming the scope's position during the procedure or the patient's discomfort. In addition, it provides a portable training platform known as the GI express. Moreover, complicated clinical procedures, such as emergency GI bleeding, can be practiced; if additional modules are purchased, training in EUS and ERCP may be beneficial.[68] For ERCP, split-screen endoscopic and fluoroscopic views are provided, and 18 virtual patient cases with diverse anatomy and pathology of the common bile duct and pancreatic duct are presented. The model is the only VR simulator capable of performing ERCP therapy (sphincterotomy, stone extraction, stent placement, etc.). However, it has a significant disadvantage in that it is difficult to purchase because it is more expensive than the simulators we have described above.

Among 28 residents without prior endoscopy experience, the group that received additional simulator training with a GI mentor prior to conventional training was compared with the group that only received conventional training. The duodenal insertion time was significantly shorter in the group of residents who received simulator training prior to conventional training, and their technical accuracy was significantly higher, demonstrating the effectiveness of this simulator.[54] However, in one study, the Texas Association of Surgical Skills Lab and Simbionix collaborated to evaluate the feasibility and effectiveness of a simulation and web-based endoscopic training curriculum, and 41 participants from four institutions who participated in this training program demonstrated a significant reduction in cecal intubation time.

A study evaluated the face and construct validity of the GI Mentor II for ERCP training.[55] Twelve participants (six novices and six experts) completed two simulated ERCP cases after 30 min of standardized simulator practice in the presence of a single proctor. Two simulated cases required procedures, such as common bile duct brushing, balloon dilatation for stricture, sphincterotomy, and stent placement. The average rating of the simulator by the participants was as follows: graphics (moderately realistic), accuracy (like clinical ERCP), difficulty (similar to clinical ERCP), and overall realism (moderately realistic). The total procedure time for each case was significantly shorter in the expert group than in the apprentice group, demonstrating construct validity. However, there was no significant difference between the two groups with regard to other metrics, including the time to reach the papilla, fluoroscopy time, number of attempts to cannulate the papilla, number of cannulations of the pancreatic duct, and contrast injection of the pancreatic duct. When the outcomes of the two selected cases were analyzed together, a significant difference was observed in the total procedure time, time to reach the papilla, and fluoroscopy time. The self-assessment scores also improved significantly after training. This shows that the endoscopic education curriculum using this simulator improves both the subjective and objective skills of apprentices.[56]

3) EndoSim

Surgical Science has created a VR model that can implement EGD, ERCP, and colonoscopy (EndoSim; Surgical Science, Sweden; https://surgicalscience.com/simulators/endosim/). In the case of colonoscopy, one can experience cases of difficult cecal insertion and learn about biopsies and polypectomy. As various types of loops and anatomical colon structures can be implemented, this model is especially useful for endoscopy novices. The ERCP module emphasizes bile duct cannulation training. After inserting the duodenum with a fluoroscope, cannulation of the bile duct in the ampulla of Vater can be practiced using split-screen endoscopic and fluoroscopic imaging. A simulation of the actual ERCP was created and includes manipulation of the guidewire and sphincterotome and injection of dye. Studies demonstrating the clinical effectiveness of this simulator have not yet been published.

4) EndoVision

Similar to other products, EndoVision (K.K. MedVision, Tokyo, Japan; https://www.medvisiongroup.com/endovision.html), which is MedVision's VR model, includes EGD, bronchoscopy, and colonoscopy modules. In the case of colonoscopy, modules pertaining to cecal intubation, such as healthy participants and loop-shaped colons, are loaded. In addition, modules are presented for diagnostic cases encountered in clinical settings, such as polyps, Crohn's disease, ulcerative colitis, diverticulosis, and ischemic colitis. By presenting different types of polyps, it is possible to receive assistance in acquiring the treatment endoscope, and this simulator can access actual proficiency. Nonetheless, no clinical studies of this simulator have been reported to date.

ESTABLISHING A NOVEL SIMULATOR-INCORPORATED ENDOSCOPY TM

As previously explained, the SBTM is effective in GI endoscopy education. However, depending on the type of the simulator, there are numerous common or significant disadvantages; thus, the SBTM alone is insufficient to completely replace the ABTM.[1,4,8,9,14,29] There have been diverse attempts to develop a novel simulator-incorporated endoscopy TM, such as simulation-based mastery learning,[14,30] progressive learning model,[69] hybrid simulation model,[29] integrated simulation,[45,70,71] task deconstruction,[18,20] and gamification[69,72]; however, the results of these developments have not yet been widely acknowledged. Nonetheless, it is desirable to develop and operate a modified TM that actively incorporates the simulator until a simulator with high validity and easy accessibility is developed that can completely replace the existing ABTM. An ideal modified TM would be an integrated TM in which the SBTM and other TMs, especially the improved ABTM, are coordinated to complement each other based on the conditions of each country and institution, and the trainee's progress.

CONCLUSIONS

This article reviewed simulators for GI endoscopy training that were available by the end of 2021. The SBTM is effective in GI endoscopy education, but there are numerous areas for improvement; therefore, the current SBTM is insufficient to fully replace the ABTM. Until a high-validity and easy-to-use simulator that can completely replace the current ABTM is developed, it seems preferable to use a simulator-integrated and well-coordinated TM that fits the needs of each country and institution.

Conflicts of Interest

Gin Hyug Lee is the developer of the EGD Method Trainer, Scope Handling Trainer, PEG Trainer, EVL Trainer, and Left-Hand Trainer, as well as a shareholder of Anymedi Inc., Seoul, Korea, as mentioned in the review paper. The other authors have no conflicts of interest to declare.

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