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# Low-cost Colonoscopic Simulator and Colonoscope to Train Basic Skills in Colonoscopy during Undergraduate Studies

João Henrique Sendrete de Pinho[1] Lorrane Vieira Siqueira Riscado[1] Marcos Paulo Moreira Sales[1] Gabriel Seixa de Souza[1] Abner Ramos de Castro[1] Cristiane de Souza Bechara[1]

[1] Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil

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**Address for correspondence** João Henrique Sendrete de Pinho, MS, Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil (e-mail: joaohenriquepinho@gmail.com).

## Abstract

**Objective** To develop a low-cost simulator model and a colonoscope with materials that are easily accessible to offer training on colonoscopy skills during undergraduate studies. Since this is the procedure of choice for colorectal cancer screening, the general practitioner must be able to recognize its main indications, preparation, and complications.

**Methods** Using materials such as a mannequin, a vehicle inspection camera, a conduit, polyvinyl chloride (PVC) pipe, acrylic, wood, and red paint, we built a simulator and a 150-cm long and 20-to-25-mm thick colonoscope. The colonoscope's handle and handhold were made of acrylic, the colonoscope's mobile end was made with articulated PVC rings, and the up and down movements were performed according to the traction of the steel cables. The camera attached to its distal end enables connection to a smartphone to view the image. In the simulator, the conduit was inserted into the mannequin to simulate the curvatures of the colon. Red spray paint was used to simulate the staining of the colonic mucosa in the inner region of the mannequin and the adventitial layer in the outer region.

**Results** We were able to build a simulator and a colonoscope with a total amount of R $ 182.82 (roughly US$ 36.50). Both were tested and proved to be useful in the acquisition of psychomotor and cognitive skills in colonoscopy.

**Conclusion** The simulator and colonoscope developed by us are cost-effective, useful in the acquisition of psychomotor and cognitive skills in colonoscopy, and can facilitate the structuring of a training program for undergraduate students.

**Keywords**
- colonoscopy
- simulation
- colonoscope
- simulator
- medical education

## Introduction

Colorectal cancer (CRC) is the third most lethal cancer in women and the fourth in men in Brazil.[1]

Although the mortality rates for CRC show a downward trend in most developed countries, increasing rates are expected in Brazil until the year 2025.[2,3] Screening for CRC is essential to diagnose and remove premalignant CRC

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lesions, reducing mortality from this type of neoplasm.[4] Currently, the American Cancer Society screening guidelines recommend initiation of screening for all adults at usual risk at 45 years of age and older.[5]

Colonoscopy is considered the gold standard diagnostic method for colon diseases, and the most effective procedure for CRC screening compared to other types of tests such as the fecal occult blood test, barium enema, and computed tomography (CT).[6,7] Through colonoscopy, which enables a complete examination of the mucosa, we can identify and remove polyps, and perform tumor biopsies, as well as diagnoses, and monitor other lesions.

However, as it is an invasive test, postcolonoscopy complications occur in approximately 0.35% of patients, and may be related to bowel preparation, sedation, the diagnostic evaluation of the colon, or the therapeutic techniques established.[8] The success of the exam depends on several important factors, and the experience of the colonoscopist, adequate indication, adequate follow-up after the exam, and the quality of bowel preparation must be highlighted[9,10]

In the Brazilian health system, colonoscopy is not always requested by a specialist, but we have observed that a small proportion of general practitioners have adequate knowledge about the examination technique, the need for preparation, and the risks and benefits to the patient.

It is also important that the patient is informed, preferably by the doctor who requested the exam, about the conditions in which the procedure is performed and all the steps involved in the process, the reason why it should be carried out and what the expected result is, what are the risks involved in carrying out the exam, the need for an assessment of the cardiac risk due to the sedation, the need to discontinue the intake of certain medications, and the importance of bowel preparation for the final result and quality of the exam.

In medicine schools, we find it difficult to offer a scenario in which the student can have this experience in colonoscopy, since it is a specialized exam, often carried out in reference centers or in tertiary hospitals.

In this context, teaching by simulation has its importance ratified, since it is a method that enables the integration of theory and practice, providing meaningful learning through the active involvement of the student. Therefore, the learner needs to mobilize knowledge, make decisions, and perform actions to solve the proposed problems. In addition, the simulation environment is safe and secure, and enables the student to repeat the same action several times.

After each situation, the teacher offers feedback to the student, provoking a reflection and developing critical and reflective thinking. Thus, the quality of care and patient safety are improved.[11]

To provide this simulated practical training, we face difficulties due to the high cost of simulators and especially colonoscopes. Although there are low-cost colonoscopy simulator models in the literature, so far there is no low-cost colonoscope that enables the implementation of practical colonoscopy activities in public educational institutions.[12,13]

Therefore, the objective of the present study was to develop a low-cost colonoscope and colonoscopy simulator model with easily-accessible materials to train technical and cognitive skills associated with colonoscopy during undergraduate studies. Thus, we can offer undergraduate students the basic motor skills to perform the procedure, in addition to creating a context for the development of cognitive skills, such as understanding the limitations, complications, and indications of the exam, interpreting the results, recognizing the importance of CRC screening programs, and teaching screening protocols. In addition to these, communication skills can also be taught, such as patient guidance on preparation, and communication about the occurrence of complications and test results.

## Methods

### Low-Cost Colonoscopy

To build the low-cost colonoscope, we used a vehicle inspection camera, 1.5 m of 1/2" hose, 5 cm of 3/4" polyvinyl chloride (PVC) pipe, 7 cm of 1/2" PVC pipe, 165 $cm^2$ of acrylic, 3 m of 2-mm coated steel, 24 M3 screws, 12 M3 non-locking and 2 locking nuts, 2 M2 screws with nuts, 6.25-mm spacers, 13 3-mm wood screws, 6 wood studs, 1 M5 screw, 1 wood cylinder with 12 mm in diameter and 25 mm in height, 1 nylon clamp, 2 1/2" U clamps, electrical tape, and instant glue. The manufacturing process was manual, using tools such as a bow saw, sander, drill, pliers, and screwdrivers, totaling 40 hours of work. (►**Table 1**).

The colonoscope was designed with a length of 150 cm and a thickness of 20 mm to 25 mm (►**Figure 1A-B**). The colonoscope's handle and handle were made of acrylic, and were a circle with 6 cm in diameter and finger notches and a $4 \times 5 \times 15$ cm trapeze respectively. (►**Figure 1C-D**). The mobile extremity of the colonoscope was made with 6 articulated PVC rings, and the up and down movements were performed according to the traction of the steel cables attached to the shaft of the handle (►**Figure 1E-F**). The camera attached to the distal end has a USB/micro-USB cable running through the entire interior of the device to be connected to a smartphone or notebook computer (►**Figure 1A-B**).

### Low-cost Colonoscopy Simulator

To build the low-cost simulator, we used a half-body dummy, a 2" conduit with 0.5 m, 8 cm of 1/2" PVC pipe, 8 nylon clamps, 2 hinges, 1 latch, 14 10-mm M3 screws with nuts, 2 80-mm M8 screws with nuts, 1 2" sewer cap, 1 eucalyptus board ($60 \times 10 \times 3$ cm), thermosetting adhesive, instant glue, and red spray paint. The manufacturing process was manual, using simple tools such as a bow saw, drill, pliers, and screwdrivers, totaling 12 hours of work. (►**Table 2**).

Nylon clamps were used to secure the conduit to the dummy, while hinges and latches were used to enable easy opening of the abdomen (►**Figure 2A**). The conduit was bent to simulate the curvatures of the colon and inserted into the dummy in the region of the abdomen and pelvis. The initial part of the conduit was glued with the thermosetting adhesive in a circular hole with 5 cm in diameter in the lower part

 

**Table 1** Detailed cost sheet of the colonoscope

| | Material | Amount | Price |
|---|---|---|---|
| **Colonoscope** | Vehicle inspection camera | 1 unit | R$ 35.00 |
| | 1/2 inch water hose | 1.5 m* | R$ 5.10 |
| | Nylon clamp | 1 unit | R$ 0.50 |
| | 25-mm spacers | 6 units | R$ 20.40 |
| | 1/2 inch U-clamps | 2 units | R$ 0.80 |
| | 10-mm M3 machine screws | 20 units | R$ 5.00 |
| | 16-mm M3 hex screws | 4 units | R$ 1.20 |
| | Hex nuts with M3 locks | 2 units | R$ 0.50 |
| | 3-mm 20-mm Phillips wood screws | 3 units | R$ 1.20 |
| | 3-mm 10-mm Phillips wood screws | 6 units | R$ 0.36 |
| | 10-mm Phillips M2 machine screws | 6 units | R$ 6.30 |
| | 10-mm M2 machine screws with nuts | 2 units | R$ 2.30 |
| | 2-mm 5-mm Phillips wood screws | 4 units | R$ 0.20 |
| | MA M3 ZB Hex nuts | 12 units | R$ 0.84 |
| | 20-mm Phillips M5 machine screw | 1 units | R$ 0.42 |
| | 3/4 inch polyvinyl chloride (PVC) pipe | 5 cm* | R$ 0.50 |
| | 1/2 inch PVC pipe | 7 cm* | R$ 0.30 |
| | 6-mm acrylic | 165 $cm^{2*}$ | R$ 7.80 |
| | Insulating tape | 1 unit | R$ 4.50 |
| | Instant glue | 1 unit | R$ 5.50 |
| | Wooden python (14 × 30) BC small | 6 units | R$ 0.90 |
| | 2-mm coated steel cable | 3 m* | R$ 5.53 |
| **Total** | | | R$ 105.15 |

*Proportional price; US$ 1 is roughly R$ 5.4.

of the dummy, which was used to simulate the anus and the rectum. The PVC pipe was used to simulate the ileocolic junction. The sewer cap was used to simulate the cecum, and it was fixed with instant glue after the ileocolic junction at the end of the conduit. Red spray paint was used to simulate the staining of the colonic mucosa in the inner region of the manikin and the adventitial layer in the outer region. (►**Figure 2B**). The dummy was fixed to the eucalyptus board in the left lateral decubitus position with M8 screws.

## Results

It was possible to develop a colonoscopy simulator worth R$ 77.67 and a low-cost colonoscope worth R$ 105.15, totaling R $ 182.82 (roughly US$ 36.50). The colonoscope has a length of 150 cm and a range of up and down movements of 150°, which are performed using the manual control on the handle. The vehicle inspection camera is only 7 mm in diameter, with good lighting and image quality, in addition to having the convenience of enabling the connection of the cable to a computer or cell phone, facilitating training. The low-cost colonoscope was used by a coloproctologist to perform the colonoscopy on the simulator. Technical maneuvers such as torque, pushing and pulling, up and down movements, and 360° visualization of the mucosa were applied, demonstrating the effectiveness if the simulator in training motor skills, enabling professors to offer the student challenges similar to those of a real colonoscopy.

The low-cost simulator was also tested with a real colonoscope (►**Figure 3A-B**), and it proved to be useful in the acquisition of motor skills. With both the low-cost colonoscope and the real colonoscope, it was possible to perform the complete colonoscopy in the simulator. The colonoscope and simulator created have low fidelity; however, due to the way they were created, they offer realism to the learner.

## Discussion

Colonoscopy is the gold standard procedure for CRC diagnosis and screening, and it is essential to reduce the rate of mortality from this type of neoplasm.[6,7] The experience of the colonoscopist is decisive to guarantee the quality of the exam, and, according to the American Cancer Society, about 140 supervised colonoscopies are needed for a colonoscopist to be considered experienced, which demonstrates the long learning curve of the procedure.[9]

Competence in colonoscopy brings together psychomotor and cognitive skills, such as the ability to perform the exam,

 

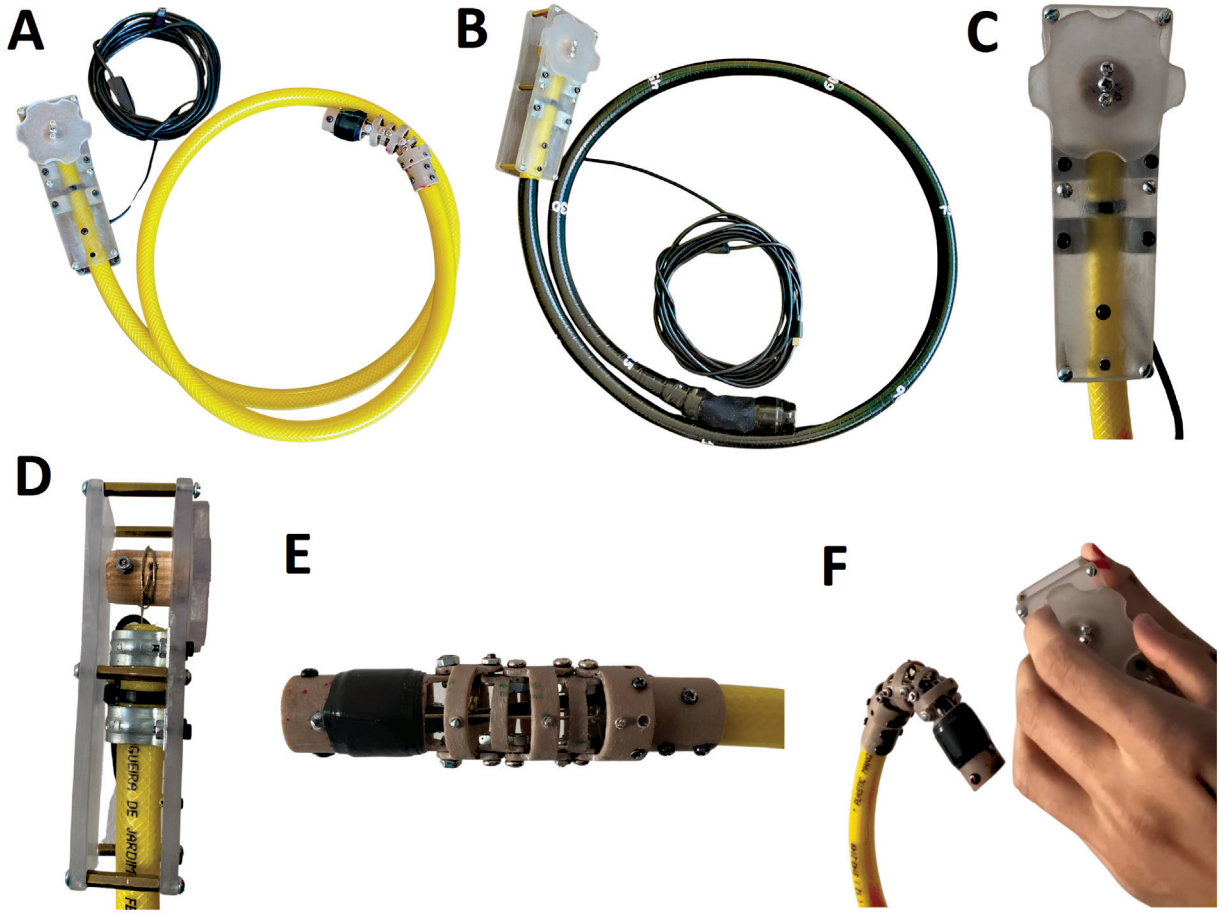


**Fig. 1** (**A**) Low-cost colonoscope built with garden hose, PVC pipe and acrylic. (**B**) Coating with insulating tape and length graduation. (**C**) Acrylic handle and grip. (**D**) Wooden shaft coupled to the handle with steel cables fixed on both sides. (**E**) Mobile end made with PVC rings. (**F**) Range of motion of the low-cost colonoscope.

**Table 2** Detailed cost sheet of colonoscopy simulator

| | Material | Amount | Price |
|---|---|---|---|
| **Colonoscopy simulator** | Half-body mannequin | 1 unit | R$ 25.00 |
| | 2-inch conduit | 0.5 m* | R$ 4.25 |
| | 1/2 inch polyvinyl chloride (PVC) pipe | 8 cm* | R$ 0.32 |
| | Nylon clamps | 8 units | R$ 4.00 |
| | Hinges | 2 units | R$ 1.40 |
| | Latch | 1 units | R$ 2.10 |
| | 10-mm M3 screws | 14 units | R$ 2.80 |
| | 80-mm M8 screws | 2 units | R$ 5.36 |
| | 2-inch sewer cap | 1 unit | R$ 7.79 |
| | Eucalyptus board | 0.603 $m^{2*}$ | R$ 3.51 |
| | Thermosetting adhesive | 1 unit | R$ 4.39 |
| | Instant glue | 1 unit | R$ 2.75 |
| | Red spray paint | 1 unit | R$ 14.00 |
| **Total** | | | R$ 77,67 |

*Proportional price; US$ 1 is roughly R$ 5.4.

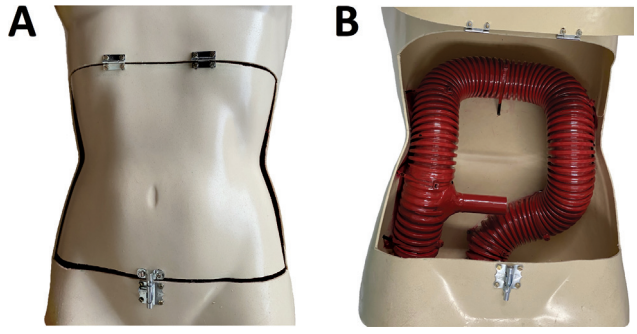


**Fig. 2** (**A**) Low-cost colonoscopy simulator. (**B**) Lower gastrointestinal tract made with conduit.

its indication, and how to guide the patient regarding the importance of the exam and the reason for the indication, the correct preparation for the procedure, and the main complications.[7] Bowel preparation is one of the most frequent reasons why patients are opposed to participating in screening colonoscopies, and inadequate preparation is a major obstacle to achieving a quality colonoscopy.[10] These skills should not only be taught to the specialist physician, but also to the general practitioner.

 

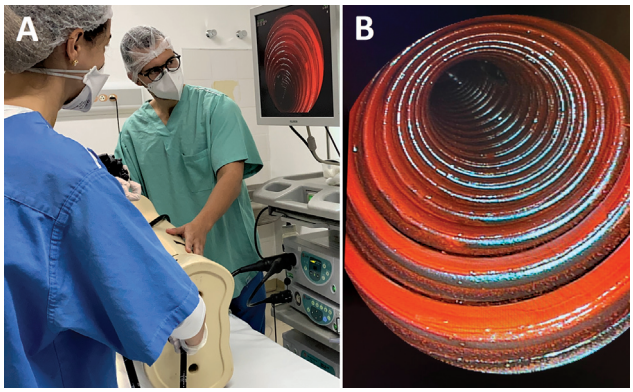


**Fig. 3** (A,B) Low-cost colonoscopy simulator test with a real colonoscope by a coloproctology specialist.

In the current scenario, some weaknesses can be pointed out in medicine courses, such as the difficulty in inserting the student in the practice scenario. In this structure, in which the student has contact with theory to later have contact with practice, the information may seem out of context, as there is no immersion in practice and recognition of the difficulties of the exam, such as the formation of loops in the flexible tube of the test colonoscope, which can trigger colon perforation.[14]

As such, it may impair the recognition of an exam complication. On the other hand, a simulation environment promotes a context that influences how students identify and perceive information, how they interpret it and how they act on the information available in learning situations, improving content retention.[15]

Simulator training is now considered a safe, efficient, and more cost-effective environment for colonoscopy training. However, high-fidelity simulators still have a high cost for the reality of public educational institutions and colonoscopes are excessively expensive to be used in training.[16] Our model costs approximately 1% of the price of a real colonoscope, which can make it possible to structure a practical context to teach colonoscopy at the undergraduate level.

By creating this low-fidelity model, we can promote a complete teaching-learning process of the skills involved in performing colonoscopies. The low-cost colonoscope could be used for the student to acquire motor skills, including the basic structure of the colonoscope's functioning, the positioning of the patient (left lateral decubitus) and the examiner, the movement techniques of the device (up, down, push, pull, and torque), in addition to cognitive skills such as the importance of viewing the mucosa in 360° when removing the device and the minimum time to remove the device, as well as the technical difficulties that can culminate in examination complications.

Active methodology techniques using the low-cost simulator and colonoscope, such as role play, can be applied to acquire communication skills, such as informing the patient about the indication for the exam or guiding the preparation. Dramatization can be a resource used in the development of an affective skill, such as communicating to the family the complication of the exam or the finding of a neoplasm during the exam, for example.

The simulator has limitations, given its low fidelity. In this sense, it is not possible to identify and extract lesions as in high-fidelity simulators. As for the colonoscope, its reduced amplitude and absence of a handle for right and left lateral deviations when compared to the real colonoscopes makes it difficult to pass the device completely and visualize the mucosa completely, making it necessary to use the torque maneuver in several situations. Comparing the performance of the real colonoscope and the low-cost one on the simulator, we noticed that the lower thickness and smoother outer coating of the real colonoscope made it easier to perform a full colonoscopy in the low-cost simulator. Although both showed a good image of the mucosa, it is necessary to consider that the simplicity of the low-cost colonoscope offers a greater challenge to perform a colonoscopy, mainly due to the lack of resources available in the real device.

Despite this, the low-cost colonoscope provides the opportunity to develop critical and reflective thinking in students. The skills acquired during the simulated activities can be improved and applied during internship, in the outpatient clinics of specialties such as gastroenterology and coloproctology, as well as in the colonoscopy centers, improving the qualification and safety to solving patient problems in the clinical environment.

With well-defined learning objectives, we can divide training into different modalities, for undergraduates and interns alike, in order to optimize learning and maximize the educational benefits of low-fidelity simulation.

## Conclusion

The low-cost simulator and colonoscope developed by us are cost-effective for the acquisition of basic colonoscopy skills when compared to high-fidelity simulators and real colonoscopes. This reduction in the cost of the device and the simulator can facilitate the structuring of a training program for academics to acquire psychomotor and cognitive skills in colonoscopy. Thus, with adequate knowledge about indications, guidelines, complications and steps to follow in the procedure, the general practitioner can contribute to the success of this test, which is extremely important for CRC screening.

### Conflict of Interests

The authors have no conflict of interests to declare.

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