Evaluating the efficiency of a colonoscopy procedure

-Guruprasad Raghavan

Advisors:
Dr. Shyam Thakkar, MD
Dr. Yang Cai, PhD

Introduction:

The lifetime risk of developing Colorectal Cancer (CRC) is 1 in 21 for men, and 1 in 24 for women. As Colorectal Cancer (CRC) is becoming one of the leading causes of cancer-death, colorectal cancer screening has become more important than ever before. Colonoscopy is accepted as the gold standard for early detection and treatment of early stage CRC.

Colonoscopy is a test that allows the doctor to view the inner mucosal lining of a patient's large intestine (ie the rectum and colon). This is achieved by using a thin, flexible tube called a colonoscope. It has a typical length ranging from 130 cm, all the way upto 170 cm, with an outer diameter of ~13mm. The probe has a forward direction of view, with a field of view of close to 140^{o}. A small video camera is attached to the tip of the colonoscope, which transmits a video image from the insides of the colon to a monitor, to carefully visualize the large intestine. Apart from a camera channel, there is an irrigation channel and a suction channel to clean the colon for a better observation of the interiors. Scopes usually house a 3.7mm wide biopsy channel as well, that enables the doctor to sample abnormal tissues for further analysis. The three sections of the colon observed by the doctor are, the ascending colon, transverse colon and the descending colon.

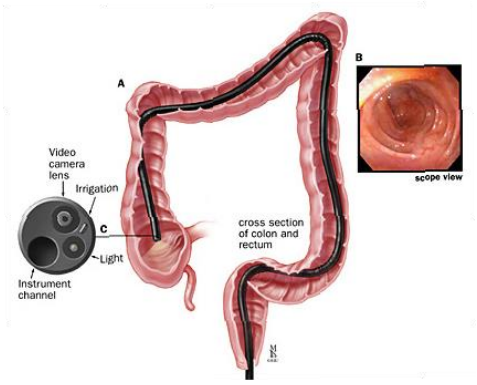


Figure 1: A cartoon that highlights the entire colonoscopy procedure

This procedure is commonly performed to detect

- Regions of high inflammation (colitis)
- Precancerous growths in the colon/rectum (polyps)
- Abnormal pouches in the Large intestine (diverticulosis)
- Areas of bleeding

Having established that viewing the colon is essential for detection or prevention of early stage CRC, it is highly essential that the colon be studied thoroughly by the endoscopist. The effectiveness of a colonoscopy procedure can be measured by the following "qualitative" metrics":

1. Observation of a “clean” colon with good contrast between abnormalities and healthy tissue features
2. Adequate visualization of the entire colon
3. Diligence during examination of the mucosa

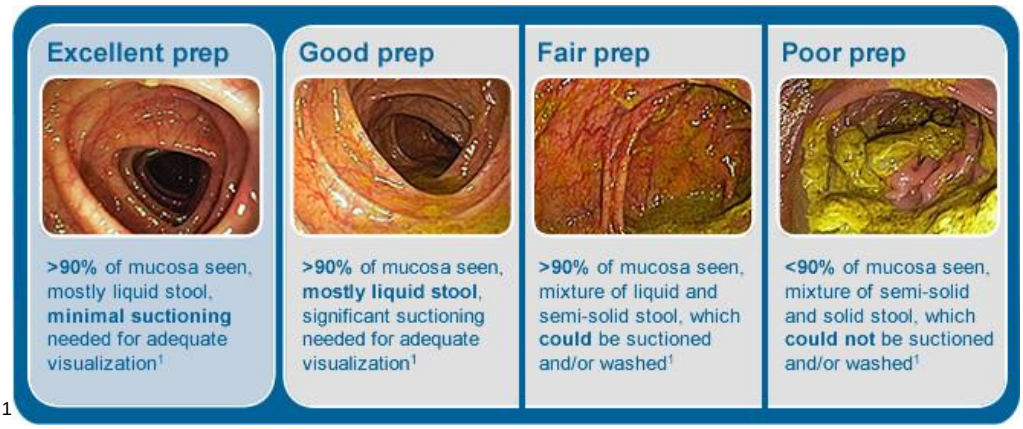
Each one of these qualitative metrics can be translated to quantitative formulations, which can further be converted into technological advancements for bettering current practice.

“Cleaning” the colon

Bowel preparation

In order to observe the colon for the detection of polyps, high inflammation zones or other kinds of abnormality, the colon needs to be clean, ie devoid of fecal material. This is achieved by recommending a “bowel preparation” phase for the patient, where he/she is advised not to have solid foods for 2-3 days before the procedure, and instead consume clear fluids like tea, water and a few others. Along with that, the patient is advised to get off medications like ibuprofen, naproxen or other blood-thinning medicines.

On following the above guidelines strictly, we can satisfactorily reduce the amount of fecal material in the colon, hence exposing a larger surface area of the mucosa for observation.



[1]

Adequate Visualization of the entire colon

While inserting the colonoscope through the colon, there is a high possibility of seeing some regions of the colon in high detail, and ignoring others completely. Apart from that, there is a high risk of not viewing the complete colon, which could occur when the scope hasn’t traversed through the three sections of the colon, or if it hasn’t reached the start of the ascending colon. This is termed as Cecal intubation rate. A common statistic on the Cecal intubation rate states that a good endoscopist traverses all the way to the cecum in >90% of his cases.

Diligence during examination of the mucosa

Mere observation of the entire colon isn’t sufficient. It is essential that the endoscopist adjust the contrast, levels of blurredness and cleanliness (by constant irrigation and suction) to increase

[1] Prep image source: https://moviprep.salix.com/hcp/colorectal-cancer-detection

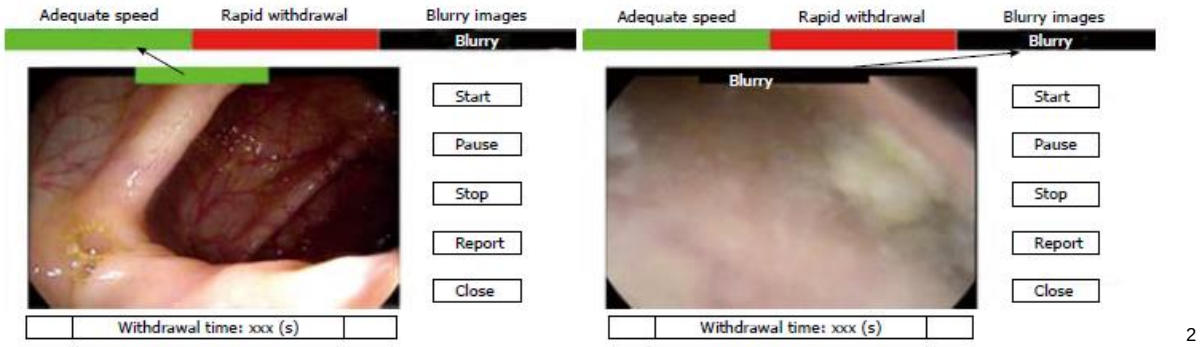
the probability of detecting regions of abnormality. The diligence of the examination can be determined by quantifying:

- The % of blurred frames in the video
    - The more the blurred frames, the poorer the observation
- The % of colon observed (with-respect-to various sectors viewed)
- Mean withdrawal rate (of the colonoscope)
    - Faster the withdrawal rate, the less keener the observation of the mucosal layer

Technological Enhancements:

As a typical endoscopist performs ~20-25 procedures on average, it is essential that he/she be provided with tools to ensure adequate visualization of the entire colon and track his diligence on each of the procedures. A report after completion of each procedure with suggestive improvements as feedback would be useful, but it is observed that real-time feedback during the procedure is more valuable.

During the withdrawal of the colonoscope, it is useful for the colonoscopist to have a sense of the withdrawal rate and the sectors of the colon observed, in real time, so that the endoscopist can make quick amends, if required.



[2]

As shown in figure 3, the colometer (an add-on software) provides real-time assessment of each frame in the video, ie indicates whether the withdrawal is adequate or rapid by a differencing technique, or determines if the image is blurry by convolving the image with a LoG filter and determining the pixel with maximum brightness as a proxy for blurriness of the image.

Results and Discussion

Dr. Cai's group at CMU have been working on developing a software that tracks the distance traversed by the colonoscope, and the observable surface area at every frame to assess the quality of the colonoscopy exam.

Testing Correctness and Robustness of the Algorithm

I worked on assisting the team with improving the algorithms developed, by testing their robustness and correctness. In order to test the correctness of the distance-measurement

[2] Filip D, Gao X, Angulo-Rodriguez L, et al. Colometer: A real-time quality feedback system for screening colonoscopy. *World J Gastroenterol*. 2012;18(32):4270-4277. doi:10.3748/wjg.v18.i32.4270

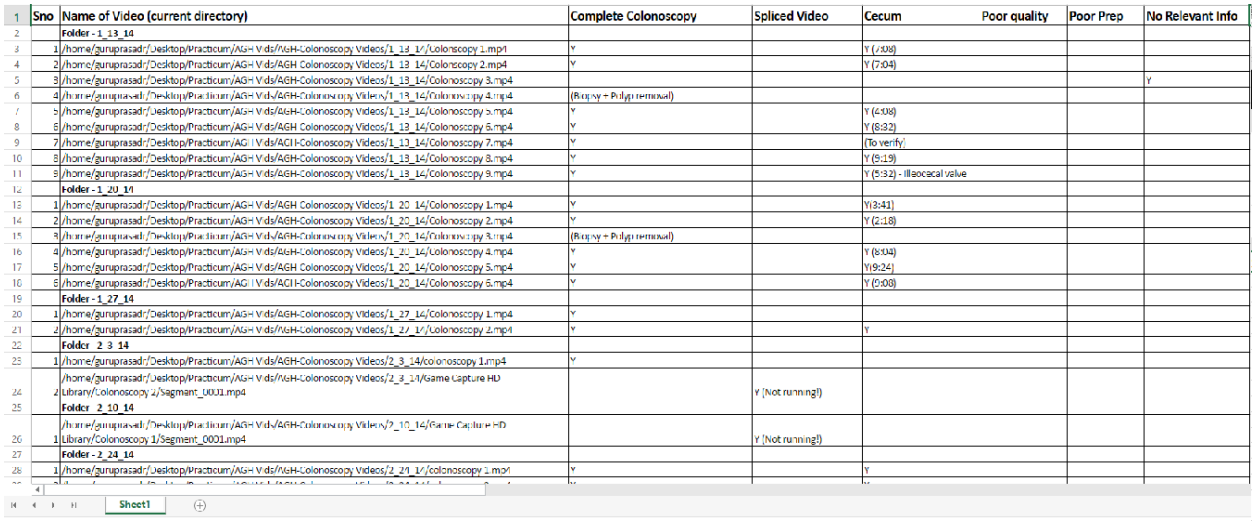
algorithm, I provided the team with snipped video segments of a pre-defined length (5cm, 10cm,15cm etc). These length measurements were vocally annotated by the endoscopist, while performing the procedure. The robustness was tested by providing the algorithm with a pig's colon as the input.

As the distance measurement is obtained by estimating the high frequency changes in the image (the higher the folds, the larger the high frequency changes), the pigs colon having very less folds doesn't elicit a response from the distance-algorithm (ie distance traversed remains at 0). But, on removing the smoothing operations at the pre-processing stage, the raw video preserves some sharp changes in features, hence improving the accuracy of the distance calculation algorithm.

Classification of colonoscopy video database

The recording software installed at McCandless Endoscopy center supports simultaneous recording of video, streamed from the camera placed at the tip of the colonoscope, as well as an associated audio. Although this has made acquisition of videos extremely intuitive, classification of these videos is a mammoth task, but an essential requirement for further analysis. I approached this problem by initially trying to build a computational tool to segregate these videos, but this was a difficult problem to solve in itself. Hence, I resort to manually segregating the videos into 5 categories (not a one-to-one mapping).

1. Complete Colonoscopy
2. Spliced Video
3. Presence of Cecum (to analyse cecal intubation rate) [time of cecum appearance also mentioned]
4. Poor quality videos (sliding along the walls)
5. Poor Bowel preparation



Sno	Name of Video (current directory)	Complete Colonoscopy	Spliced Video	Cecum	Poor quality	Poor Prep	No Relevant Info
	Folder - 1_13_14						
1	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 1.mp4	Y		Y (7:06)			
2	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH Colonoscopy Videos/1_13_14/Colonoscopy 2.mp4	Y		Y (7:04)			
3	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 3.mp4						Y
4	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 4.mp4	(Biopsy + Polyp removal)					
5	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 5.mp4	Y		Y (4:06)			
6	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH Colonoscopy Videos/1_13_14/Colonoscopy 6.mp4	Y		Y (6:32)			
7	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 7.mp4	Y		(To verify)			
8	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 8.mp4	Y		Y (5:19)			
9	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_13_14/Colonoscopy 9.mp4	Y		Y (5:32) - Illeocecal valve			
	Folder - 1_20_14						
1	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH Colonoscopy Videos/1_20_14/Colonoscopy 1.mp4	Y		Y(3:41)			
2	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_20_14/Colonoscopy 2.mp4	Y		Y (2:18)			
3	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_20_14/Colonoscopy 3.mp4	(Biopsy + Polyp removal)					
4	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_20_14/Colonoscopy 4.mp4	Y		Y (5:04)			
5	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH Colonoscopy Videos/1_20_14/Colonoscopy 5.mp4	Y		Y(9:24)			
6	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_20_14/Colonoscopy 6.mp4	Y		Y (5:08)			
	Folder - 1_27_14						
1	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_27_14/Colonoscopy 1.mp4	Y					
2	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/1_27_14/Colonoscopy 2.mp4	Y		Y			
	Folder - 2_3_14						
1	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/2_3_14/colonoscopy 1.mp4	Y					
2	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/2_3_14/Game Capture HD Library/Colonoscopy 2/Segment_0001.mp4		Y (Not running!)				
	Folder - 2_10_14						
1	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/2_10_14/Game Capture HD Library/Colonoscopy 1/Segment_0001.mp4		Y (Not running!)				
	Folder - 2_24_14						
1	/home/guruprasadr/Desktop/Practicum/AGH Vids/AGH-Colonoscopy Videos/2_24_14/colonoscopy 1.mp4	Y		Y			

Sheet1

Figure 2: Classification of the videos (in a spread-sheet)

Automated Detection of Cecum

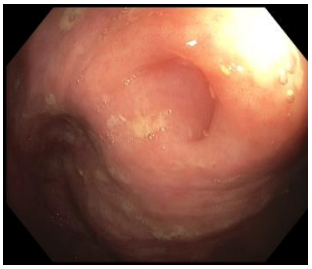
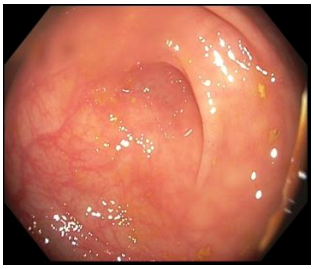
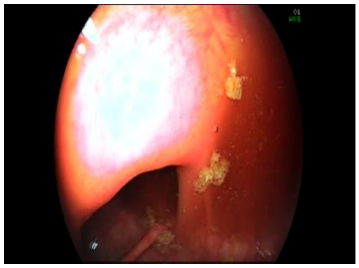
As mentioned above, it is essential that the entire colon be observed for abnormalities (for instance, presence of polyps). This can be guaranteed, if the endoscopist inserts the

colonoscope all the way until the cecum is reached. The two commonly used markers for the cecum are:

- Appendiceal orifice
- Ileocecal valve

In order to develop an image-processing algorithm to detect these markers and classify it as a cecum or not, the first step is to collect multiple cecum images for feature detection, followed by training a neural network for "learning" these features.

1. Collect Cecum Images {~50 images}

Future Work:

1. Extract significant features from the cecum (pouch-like appendiceal orifice, and the ileocecal valve) to classify if an image shows the cecum or not
2. Real-time feedback to determine if cecum has been reached or not.
3. Classify more recent videos into the 5 categories described earlier.

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