

# Analyzing the curvature of the colon in different patient positions

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## ABSTRACT

**Purpose:** Colonoscopy is a complex procedure with considerable variation among patients, requiring years of experience to become proficient. Understanding the curvature of colons could enable practitioners to be more effective. The purpose of this research is to develop methods to analyze the curvature of patients' colons, and compare key segments of colons between supine and prone positions.

**Methods:** The colon lumen in CT scans of ten patients are segmented. The following steps are automated by Python scripts in the 3D Slicer application: a set of center points along the colon are generated, and a curve is fit to these points. By identifying local maximums and local minimums in curvature, curves can be defined between two local curvature minimums. The angle of each curve is calculated over the distance of curves.

**Results:** This automated process was used to identify and quantitatively analyze curves on the colon centerline in different patient positions. On average, there are  $4.6 \pm 3.8$  more curves in supine position than prone. In the descending colon, there are more curves in the supine position, but curves in the prone position are larger.

**Conclusion:** This process can quantify the curvature of colons, and can be adapted to consider other patient groups. Descriptive statistics indicate supine position has more curves in the descending colon, and prone has sharper curves in the descending colon. These preliminary results motivate further work with a larger sample size, which may reveal additional significant differences.

**Keywords:** Colon, colonoscopy, CT, curvature, curve, supine, prone, intubation.

## 1. INTRODUCTION

Over time, it is common for people to develop colonic polyps. These are often benign for long periods of time, but can eventually become malignant resulting in diseases such as colon cancer. Colon cancer is the third most diagnosed cancer in the U.S.<sup>1</sup>, and colonoscopy is a fundamental way to prevent this through the removal of polyps, and to enable less invasive treatments by early detection<sup>2</sup>. In 2017, there were an estimated 135 000 cases of colorectal cancer diagnosed in the U.S., and it is estimated there were greater than 50 000 deaths from colon cancer<sup>1</sup>. Patients with no family history of colorectal cancer, no inflammatory bowel disease, and no history of adenomas are considered to be at average risk. For these patients colonoscopy is recommended every ten years starting at age 50, with less invasive screening methods done in-between<sup>1</sup>. However, colonoscopy can be required sooner if a less invasive test such as CT colonography does not give a conclusive negative result.

In colonoscopy, colonic polyps and other signs of risk can be identified and removed with a colonoscope inserted through the rectum<sup>3</sup> (Figure 1). After careful preoperative bowel preparation, the first stage of the colonoscopy procedure is intubation. In intubation the physician must insert the colonoscope though the full length of the colon. This involves manipulating the colonoscope to navigate through the anal sphincter and rectum, then the sigmoid colon, the descending colon, the splenic flexure, the transverse colon, the hepatic flexure, and finally the ascending colon. The physician then begins the extubation process where they examine the walls of the colon for abnormalities while retracting the colonoscope.



Figure 1. Example view of a colonoscope, created with techniques of CT virtual colonoscopy.

This procedure is complex as the colon can contain several complex turns and curves, especially in the sigmoid colon and the hepatic and splenic flexures. This complexity means the procedure is substantial in length, and it is uncomfortable for the patient. Furthermore, this procedure has considerable risks, such as perforation of the colon<sup>4</sup>. Perforation of the colon can occur when there is a significant obstacle to the colonoscope such as a sharp curve, and too much pressure is applied against the lining of the colon. In fact, the descending colon is one of the most difficult sections in colonoscopy, especially in smaller female patients<sup>5</sup>. Similarly, the hepatic flexure is a significant area of difficulty because the sharp curves can catch the colonoscope, especially in tall or obese males<sup>5</sup>. Due to these factors among others, colonoscopy is a procedure that can take years of experience and training to achieve proficiency.

Distention describes how the fluids pool in the intestine to affect visibility, and it is common practice to turn a patient to different positions during extubation to give the colonoscope an improved view of the surfaces. It was found that this increases the adenoma detection rate, is cost neutral, and adds just 44 seconds to the procedure<sup>2</sup>. In the words of Wilson *et al.*, position changes enhance the colonoscopy examination, and should be taught to trainees and observed as a metric for the trainee's proficiency<sup>2</sup>. However, the most difficult and most uncomfortable portion of the procedure is intubation<sup>5</sup>, so herein lies the most room for improvement in patient comfort.

Due to the complexity, time required for proficiency, invasiveness of the procedure, and frequency of the procedure, any information on the curvature of colons is of great use to physicians. Hence, if a quantitative understanding of the curvature of the colon for a patient group is reached, recommendations can be made for that patient group on how a colonoscopy can best be completed. This could improve the ease of operation and improve patient care. Therefore, the goal of this research is to develop a process to analyze the curvature of colons, and to make quantitative comparisons between supine and prone patient groups.

## 2. METHODS

To quantify colon curves from CT scans, the colons are first segmented. Then a curve is fitted to a set of points along the center of each colon. The curvature at every point on the curve is calculated. Maximums and minimums in curvature are located. The span between two local curvature minimum points is considered a curve. The angle of the curve is recorded, along with the length of the curve. Ten patients worth of CT data are segmented and analyzed with these methods, where for each patient there is a supine and a prone scan. Segmentation and placing cut points must be done manually using the

methods described, while the remainder of the process is automated using Python scripts that run in a 3D Slicer<sup>6</sup> extension. The implementation of calculations and full source code can be found on GitHub<sup>i</sup>.

## 2.1 Segmentation

Segmentation poses exceptional challenges for full automation, and this portion of the process is the most time intensive. This process starts with both prone and supine CT scans of patients. It uses the semiautomatic Grow From Seeds<sup>ii</sup> tool in the Segment Editor of 3D Slicer to segment the colons with the fast GrowCut algorithm<sup>7</sup> in a more time effective way. Once there are two segments made, named 'colon' and 'notColon', the 'colon' segmentation (Figure 2) is examined for small discontinuities that are connected with the 3D brush tool, in a way that preserved the original shape of the curve. Morphological skeletonization is used later in the process, and it can miss sections of the segmentations if sections lie very close to one another. Sections that lie very close to each other are fixed by shrinking margins by three cubed pixels to increase the space between neighboring sections of colon, while preserving the shape of the curves. At the end of this step the colon segment must be one continuous segment where no two sections lie too close to each other. If there are too many issues that must be corrected, the Grow From Seeds operation can be redone.

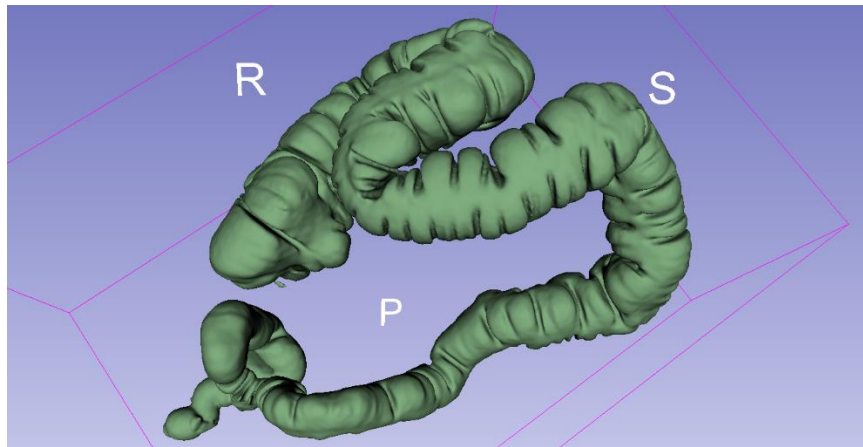


Figure 2. Segmentation of a colon.

## 2.2 Cut points

At this point, one first 'cut point' markup is placed on the straight section of the mid ascending colon, and a second on the straight section of the mid descending colon. These points will split up the colon into three sections; ascending, transverse (includes flexures), and descending (includes sigmoid). The rest of this process is fully automatic and is run by custom Python scripts in a 3D Slicer extension.

## 2.3 Center points

The Extract Skeleton<sup>iii</sup> module in 3D Slicer is a command line module that takes in a binary label map node, a number of points to generate, and an empty markups fiducial node. It will output a set of center points along the binary label map model into the empty markups fiducial node. To do this, Extract Skeleton applies a voxel based morphological skeletonization algorithm<sup>8</sup> to generate a set of center points along a model. Therefore, the colon segmentation is converted to a binary label map and Extract Skeleton is run on the colon label map, with the number of points set to 600. The Extract Skeleton module saves the generated center points (Figure 3) of the colon to a new markups fiducial list. This step is the most computationally intensive, taking up to four minutes per colon. In fact, depending on the capabilities of your system, it may be advantageous to run this process on multiple colons at once in different 3D Slicer windows to utilize more CPU cores. In this step of the process, the cut points markups fiducial nodes are converted to text files with a list of points.

<sup>i</sup> <https://github.com/PerkLab/ColonCurvature>

<sup>ii</sup> [https://slicer.readthedocs.io/en/latest/user\\_guide/module\\_segmenteditor.html](https://slicer.readthedocs.io/en/latest/user_guide/module_segmenteditor.html)

<sup>iii</sup> <https://www.slicer.org/wiki/Documentation/4.4/Modules/ExtractSkeleton>

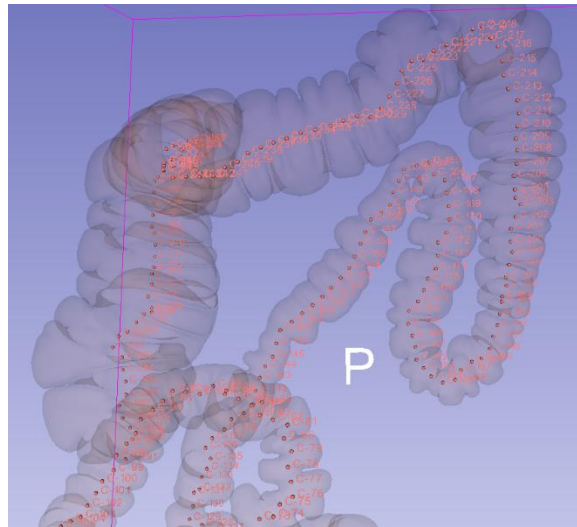


Figure 3. Center points visible in a transparent colon segmentation.

## 2.4 Curve fitting

Markups to Model<sup>iv</sup> is a loadable module in 3D Slicer that can fit a curve to a list of markups fiducial points (Figure 4). A Markups to Model node is used to fit a moving least squares polynomial with order 2, a sample width of 5% of the model length, and a radius of zero to the center points. This curve follows closely the trends of the centerline markups but avoids some of the noise created from the semilunar folds of the colon. This curve is saved as a VTK model, which contains polydata of the coordinates of approximately 1400 points along the model's length. Next, the computeCurvatures function from the Curve Maker<sup>v</sup> scripted module is applied to the VTK curve model in 3D Slicer. This function calculates the curvature at every point on the model as a list. The list of (x, y, z) coordinates is then supplemented by the list of curvatures, to form a list of (x, y, z, curvature) tuples. This list of point and curvature data is saved to a text file for analysis.

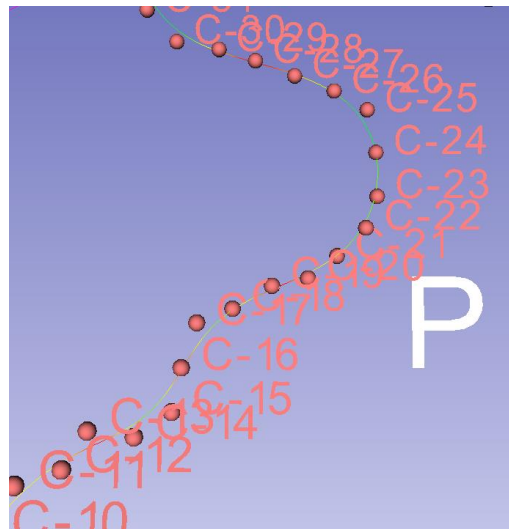


Figure 4. A curve fit to a set of center points of a colon. The curve is heat mapped to the local curvatures, where blue is high curvature and red is low.

<sup>iv</sup> <https://github.com/SlicerIGT/SlicerMarkupsToModel>

<sup>v</sup> <https://www.slicer.org/wiki/Documentation/Nightly/Extensions/CurveMaker>

## 2.5 Curve delineation

To analyze a curve, one must first define what a curve is and locate them on the model. If a point is a local maximum in curvature and has curvature greater than the average curvature multiplied by a threshold value (which is 1 by default), the that point is labelled a max. This relative thresholding prevents maximums from forming in areas of low curvature where the curvature fluctuates slightly. Minimums are found similarly, except the threshold value is multiplied by a minimum threshold boost value of 1.5 by default, to prevent minimums from forming on large curves. A perfect curve identification algorithm would generate alternating maximums and minimums. However, thresholding means this may not be so, hence all uninterrupted series of maximums are replaced by one maximum centered with respect to arc length, and similarly for minimums. This prevents multiple maximums from occurring on one curve, or multiple minimums from occurring between curves. A curve is defined from a minimum to a subsequent minimum, and there will be one maximum in each curve. Maximum and minimum points are loaded into Slicer for manual visual verification (Figure 5).



Figure 5. Maximum and minimum points on a section of the curve model.

## 2.6 Curve measurement and generating results

To quantify the change in angle of a curve, the following process is used (Figure 6). For every triple of min, max, min, a secant from the first minimum to a point two points forward is called vector A. A secant from a point two points behind the second minimum, to the second minimum is called vector B. Vector A and vector B can be thought of as tangent approximations at both minimums. Using the angle between two vectors formula, the angle when the vectors are tail to tail is the number of degrees that the line curves. The distance it curves over is the length of the vector from the first minimum to the second minimum. Metrics such as number of curves, and mean angle of curves are calculated and saved to a patient comparison file, and a comparison file for the entire sample. All data files are comma separated for easy import to Excel. Excel is used to manipulate the results files to represent and organize the statistics.

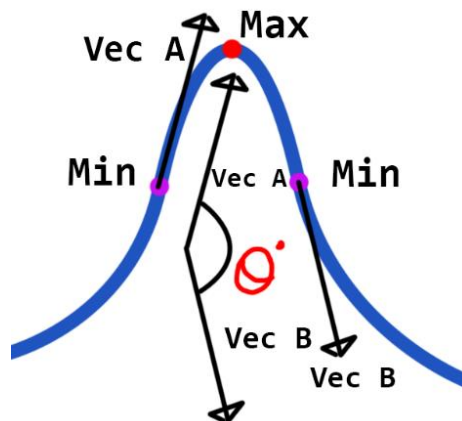


Figure 6. A diagram explaining how the angle change of a curve is measured. A curve is defined from a local minimum in curvature to the next local minimum in curvature. Vector A and B are tangent approximations at the local minimums. The angle between these vectors is the angle change of the curve.

### 3. RESULTS AND DISCUSSION

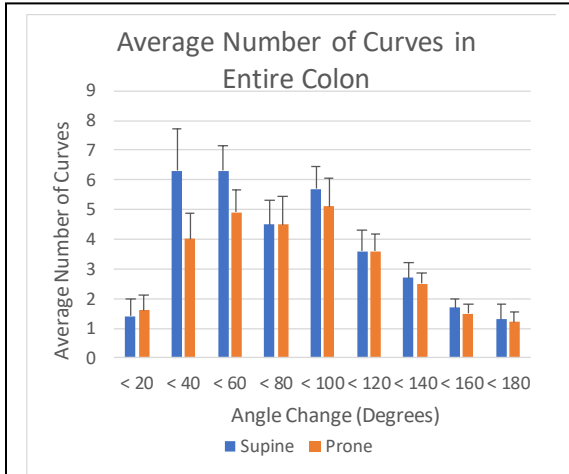


Figure 7. Histogram of the average number of curves ( $\pm$ SEM) in the entire colon per degree interval, with degree intervals of 20 degrees.

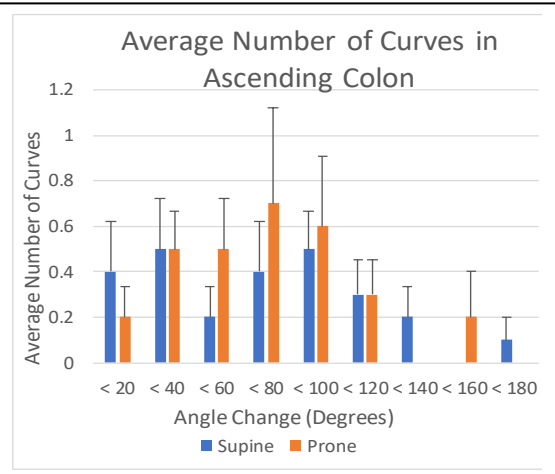


Figure 8. Histogram of the average number of curves ( $\pm$ SEM) in the ascending colon per degree interval, with degree intervals of 20 degrees.

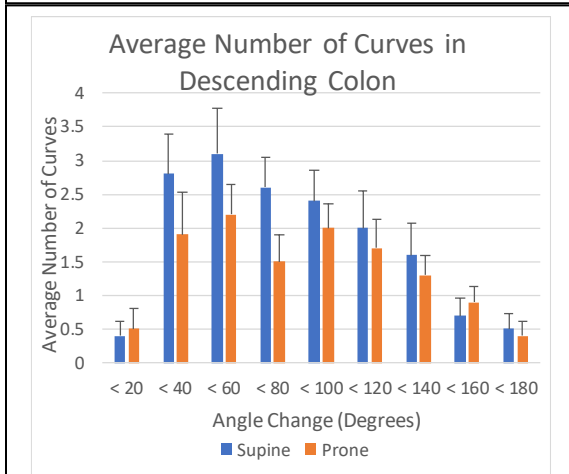


Figure 9. Histogram of the average number of curves ( $\pm$ SEM) in the descending colon per degree interval, with degree intervals of 20 degrees.

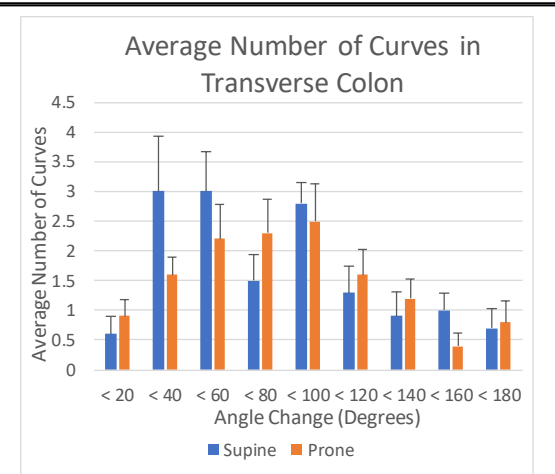


Figure 10. Histogram of the average number of curves ( $\pm$ SEM) in the transverse colon per degree interval, with degree intervals of 20 degrees.

Looking at the entire colon (Figure 7), one can observe that in each interval greater than 60 degrees the number of supine curves is equal to or greater than the number of prone curves in that interval. For intervals greater than 20 degrees and less than 60 degrees, there are considerably more supine curves with that curvature. The only interval where there are slightly more prone curves is where the angle is less than 20 degrees. Looking at the ascending colon (Figure 8), the standard error of the mean is greater than it is for the other sections. There are an approximately equal number of intervals where supine has more curves than prone, and vice versa. In the transverse colon (Figure 10), there are considerably more supine curves than prone curves combined in the intervals between 20 and 100. All other intervals are approximately equal or contain more prone curves. Most noticeably, looking at the descending colon (Figure 9) it is observed that there are considerably more supine than prone curves in every interval, less the 0-20 and 140-160 intervals. In the descending colon, the standard error of the mean values are the smallest compared to the data in that section, for all sub sections of the colon.

Table 1. Mean ( $\pm$ SEM) number of curves in each segment by position.

Mean Number of Curves	Supine	Prone
Whole Colon	33.5 $\pm$ 2.1	28.9 $\pm$ 1.7
Ascending Colon	2.6 $\pm$ 0.3	3.0 $\pm$ 0.7
Transverse Colon	14.8 $\pm$ 1.5	13.5 $\pm$ 1.2
Descending Colon	16.1 $\pm$ 2.0	12.4 $\pm$ 1.7

Table 2. Mean ( $\pm$ SEM) angle change of curves in each segment by position.

Mean Angle Change of Curves	Supine (Degrees)	Prone (Degrees)
Whole Colon	79.1 $\pm$ 5.9	81.2 $\pm$ 4.3
Ascending Colon	70.4 $\pm$ 7.5	63.8 $\pm$ 10.8
Transverse Colon	81.7 $\pm$ 8.0	81.4 $\pm$ 6.7
Descending Colon	78.2 $\pm$ 5.1	84.4 $\pm$ 3.7

There are  $4.6 \pm 3.8$  more curves in the supine position than the prone position along the entire colon (Table 1). The descending colon has the most noticeable difference between number of supine and prone curves. In the descending colon, there is a mean of  $3.7 \pm 3.7$  curves more in the supine position. However, in clinical practice, raw number of curves is not a complete picture of the difficulty of colonoscopy. Examining the magnitude of curves with the change in angle is important in assessing the difficulty of curves. See Table 2 for a summary of how the mean angle change of curves varies in each segment by position. The mean angle change of each curve in the prone position is slightly higher than that of the curves in the supine position. In the descending colon, prone curves turn a mean of  $6.2 \pm 8.8$  degrees more than supine curves.

Since this is a preliminary study and the sample size is small, there are not enough data points to perform a statistical analysis. Instead, we report descriptive statistics. There are, however, noticeable effects that could indeed be significant. The current sample size of ten patients is large enough to allow descriptive comparisons to be made, but to prove such effects are significant requires further study with a larger sample size.

Furthermore, the raw number of curves that are identified on a section of a patient's colon is not a direct mapping of difficulty of colonoscopy. Curves which curve at a sharper angle and which do so in a shorter distance will provide the most difficulty for physicians, and this should be taken further into account with future research in this direction.

#### 4. NEW OR BREAKTHROUGH WORK TO BE PRESENTED

We developed a process to analyze the curvature of colons from CT scans, and made quantitative comparisons between supine and prone positions to discover novel trends in the curvature of patients' colons. This process is fully automatic after colons have been segmented, and it can be used on a larger sample size, or to compare other patient groups. This research sets up the process for and prefaces a study of larger sample size to statistically prove useful trends and make clinical recommendations.

#### 5. CONCLUSION

Our process identified and quantified curves in the colons of ten patients' CT scans. This study highlights trends such as more curves in patients' colons in the supine position, especially in patients' descending and sigmoid colons. It is also observed that curves in the descending colon for studied patients are of a higher degree in the prone position. With the data provided in this study, and the potential future data collected from a study with a larger sample size, physicians will have a better idea of the typical curvatures of colons, to aid them in colonoscopy.

#### 6. ACKNOWLEDGEMENTS

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