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ORIGINAL ARTICLE

Morphometric analysis and tortuosity typing of the large intestine segments on computed tomography colonography with artificial intelligence.

Análisis morfométrico y tipificación de tortuosidad de los segmentos del intestino grueso en imágenes de colonografía por tomografía computarizada en combinación con inteligencia artificial.

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Abstract

Background:

Morphological properties such as length and tortuosity of the large intestine segments play important roles, especially in interventional procedures like colonoscopy.

Objective:

Using computed tomography (CT) colonoscopy images, this study aimed to examine the morphological features of the colon's anatomical sections and investigate the relationship of these sections with each other or with age groups. The shapes of the transverse colon were analyzed using artificial intelligence.

Methods:

The study was conducted as a two- and three-dimensional examination of CT colonography images of people between 40 and 80 years old, which were obtained retrospectively. An artificial intelligence algorithm (YOLOv8) was used for shape detection on 3D colon images.

Results:

160 people with a mean age of 89 men and 71 women included in the study were 57.79±8.55 and 56.55±6.60, respectively, and there was no statistically significant difference (p= 0.24). The total colon length was 166.11±25.07 cm for men and 158.73±21.92 cm for women, with no significant difference between groups (p=0.12). As a result of the training of the model Precision, Recall, and mAP were found to be 0.8578, 0.7940, and 0.9142, respectively.

Conflict of interest:

The authors declare no conflict of interest and funding

Authorship contributions:

H S conceptualization, data collection, methodology, manuscript writing and editing, literature review, formal analysis, critical review; M O manuscript writing and editing, literature review, formal analysis; M A S methodology, formal analysis; M S conceptualization, methodology

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Conclusions:

The study highlights the importance of understanding the type and morphology of the large intestine for accurate interpretation of CT colonography results and effective clinical management of patients with suspected large intestine abnormalities. Furthermore, this study showed that 88.57% of the images in the test data set were detected correctly and that AI can play an important role in colon typing.

Resumen

Antecedentes:

Las propiedades morfológicas como la longitud y la tortuosidad de los segmentos del intestino grueso juegan un papel importante, especialmente en los procedimientos de intervención como la colonoscopia.

Objetivo:

Examinar las características morfológicas de las secciones anatómicas del colon e investigar la relación de estas secciones entre sí o con grupos de edad. Las formas del colon transverso se analizaron con inteligencia artificial.

Métodos:

El estudio se realizó con un examen bidimensional y tridimensional de imágenes de colonografía por tomografía computarizada de 160 personas con edades comprendidas entre 40 y 79 años obtenidas retrospectivamente. Se utilizó un algoritmo de inteligencia artificial (YOLOv8) para la detección de formas en imágenes de colon en 3D.

Resultados:

La edad media de 89 hombres y 71 mujeres incluidas en el estudio fue 57.79 ±8.55 y 56.55 ±6.60, respectivamente (p= 0.24). La longitud total del colon fue de 166.11 ±25.07 cm para los hombres y 158.73 ±21.92 cm para las mujeres (p= 0.12). Como resultado del entrenamiento del modelo, se encontró que Precision, Recall y mAP fueron 0.8578, 0.7940 y 0.9142, respectivamente.

Conclusiones:

El estudio destaca la importancia de comprender el tipo y la morfología del intestino grueso para una interpretación precisa de los resultados de la colonografía por TC y un tratamiento clínico eficaz de los pacientes con sospecha de anomalías del intestino grueso. Además, este estudio demostró que el 88.6% de las imágenes del conjunto de datos de prueba se detectaron correctamente y que la IA puede desempeñar un papel importante en la tipificación del colon.

Remark

1) Why was this study conducted?

This study aimed to define the morphometric and variational characteristics of the large intestine anatomy subject to colorectal cancer surgery, generate data that can be helpful for surgical planning, and automatic preoperative identification of variations using artificial intelligence.

2) What were the most relevant results of the study?

Total colon and transverse colon lengths were longer at 60-69 years of age. 2) V-shaped was found to be the main type of tortuosity in the transverse colon. 3) Artificial intelligence can play an important role in colon typing and 88.57% of the images in the test data set were detected correctly.

3) What do these results contribute?

Our findings demonstrate morphometric and variational information (such as tortuosity characteristics) about the anatomy of the large intestine and the success rates in automatic recognition of these with artificial intelligence tools.

Introduction

The large intestine is a crucial part of the digestive system that is responsible for the absorption of water and electrolytes and the elimination of waste products. The anatomy of the large intestine includes the caecum, the ascending colon, the transverse colon, the descending colon, the sigmoid colon, and the rectum [1].

Although colonoscopy is the most commonly used method in colorectal examination in current clinical practice [2], the development of alternative methods is important due to preoperative preparation, the need for sedation during the operation, the discomforts experienced by patients before, during, and after the operation, the knowledge and skill of the specialist physician influencing the success of the operation, and the possibility of operational complications [3].

Radiological examination is an important tool in evaluating the large intestine anatomy, as it allows for the visualization of the structure and function of the intestines without invasive procedures. Several radiological techniques are used to examine the large intestine anatomy, including X-ray, computed tomography (CT), magnetic resonance imaging, and barium enema. These techniques provide valuable information about the structure and function of the intestines and allow for detecting abnormalities and diseases. Radiological examination is a safe, non-invasive, and efficient way to examine the large intestine anatomy and plays an important role in managing digestive disorders. CT is a more advanced radiological examination that provides a three-dimensional image of the large intestine. CT is beneficial for evaluating large intestine anatomy in many disorders (such as inflammatory bowel disease, diverticulitis, and tumors) and in cases of incomplete colonoscopy, which requires further investigation [4].

In recent years, artificial intelligence studies have been used in many fields, including medicine, to provide helpful information. Machine learning and deep learning methods help clinicians with artificial intelligence diagnostic support systems [5,6]. Artificial intelligence also makes morphological associations with morphometric features of typical anatomical structures [7].

This study aimed to assess the morphological properties (such as length and tortuosity) of the anatomical segments of the large intestine in adults using CT colonography and to investigate the relation between these parts and each other or age groups. In addition, morphological detection of the transverse colon was performed using artificial intelligence.

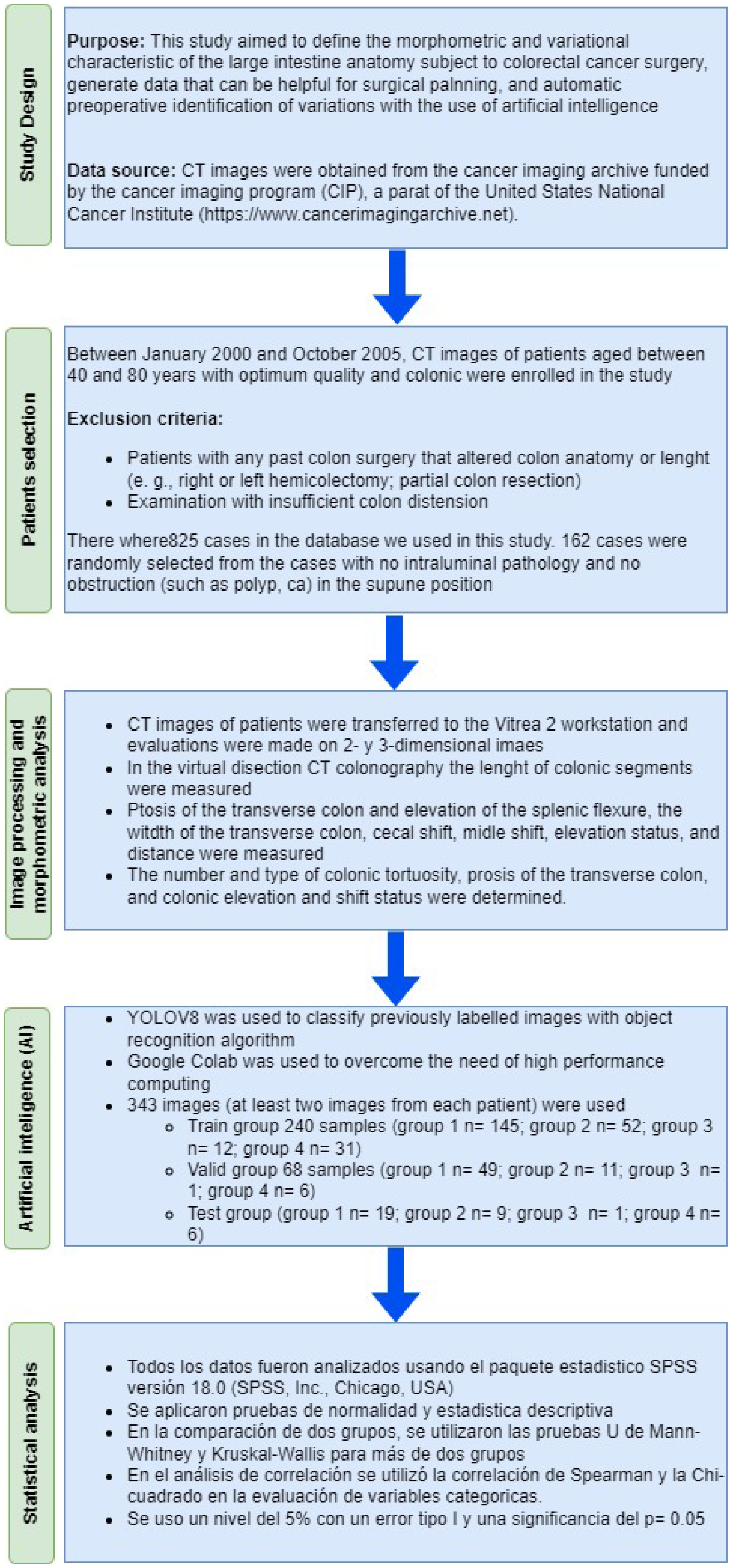

Figure 1. The methodological flowchart of the study

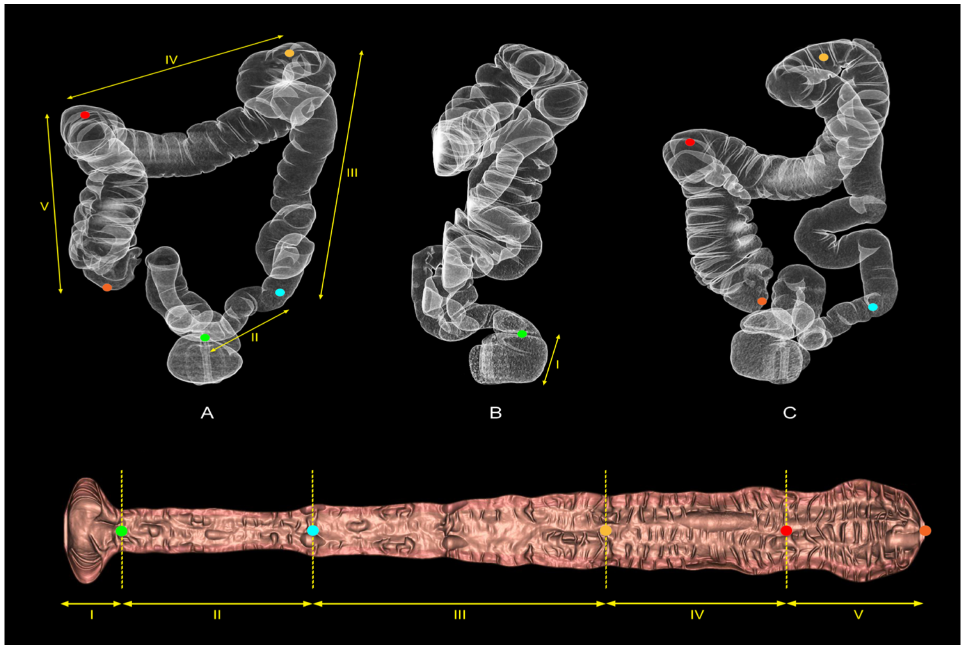

Figure 2. Three-dimensional (A-C) and two- dimensional virtual dissection images demonstrate the large intestine segments: (I) rectum (anal canal to rectum), (II) sigmoid colon, (III) descending colon, (IV) transverse colon, (V) ascending colon.

Material and Methods

The methods and a general flowchart are summarised in Figure 1.

Data source

Computed tomography images were obtained from the Cancer Imaging Archive, funded by the Cancer Imaging Program (CIP), a part of the United States National Cancer Institute (https://www.cancerimagingarchive.net/) [8].

Patient selection

The current study was designed as a retrospective study. Between January 2000 and October 2005, CT images of patients aged between 40 and 80 years with optimum quality and colonic distention were enrolled in the study. However, those with any past colon surgery that altered colon anatomy or length (e.g., right or left hemicolectomy; partial colon resection) and examinations with insufficient colon distension were excluded from the study.

There were 825 cases in the database we used in this study. One hundred sixty-two cases were randomly selected from the cases with no intraluminal pathology and no obstruction (such as polyp, ca) in the supine position.

Image processing and morphometric analysis

Computed tomography images of patients were transferred to the Vitrea2 workstation (Vital Images, Canon, Minnetonka, MN, USA), and evaluations were made on two- and three-dimensional images (Figure 2). A radiologist (11 years experience) and an anatomist (6 years experience) made an image assessment. The ptosis of the transverse colon and elevation distance measurements of the splenic flexure in 2D images with coronal section, the width of the transverse colon (wide U type), cecal shift, midline shift, elevation status, and distance were measured (Figure 3 A-C).

The number and type of colonic tortuosity in three-dimensional images, ptosis of the transverse colon, and colonic elevation and shift status were determined and evaluated. Column tortuosity

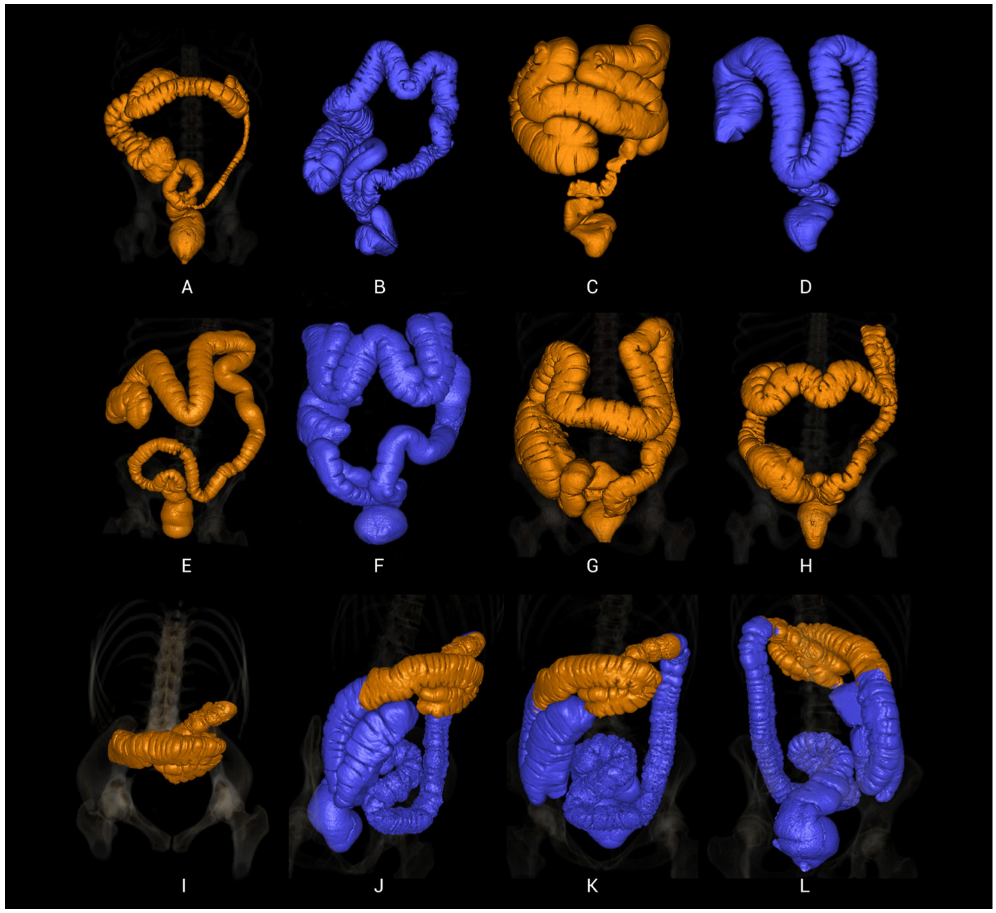

Figure 3. Types of the transverse colon depending on the morphology. (A) Boomerang-shaped, (B) M-shaped, (C) Omega-shaped, (D) U-shaped, (E) V-shaped, (F) W-shaped, (G) wide-U-shaped, (H) wavy-shaped, (I-L) Gamma-shaped.

typing was analyzed in nine groups: Boomerang-shaped, Gamma-shaped, M-shaped, Omega-shaped, U-shaped, V-shaped, W-shaped, wavy-shaped, and wide-U-shaped (Figure 4).

In the Virtual Dissection CT Colonography option on the workstation, 2D and 3D CT images are combined, using a combination of total colon length, cecum-hepatic flexure length, transverse colon length (distance between hepatic and splenic flexure), splenic flexure-distance between descending colon distal, sigmoid colon length (Distance from distal descending colon to rectosigmoid junction) and rectosigmoid length (distance from anal canal level to rectosigmoid junction) were measured (Figure 2).

Patients were divided into age groups over decades. The regions were divided into the proximal colon (the part from the cecum to the splenic flexure, including the transverse colon) and the distal colon (the segment from the splenic flexure to the level of the anal canal). The average of these two main segments was taken, and statistical evaluation was made according to gender, age groups, number of colonic tortuosity, and the types.

Artificial intelligence (AI) application

This study used the YOLO (You Only Look Once) version 8 algorithm for object recognition for shape detection on 3D colon images. This algorithm divides an input image into S x S grid cells and estimates B bounding boxes and their corresponding class probabilities for each cell. YOLO aims at fast and accurate object detection by transforming the object detection problem into a regression problem [9,10]. YOLOv8 supports multiple vision tasks such as object detection, segmentation, pose estimation, tracking, and classification and has a fast performance [11].

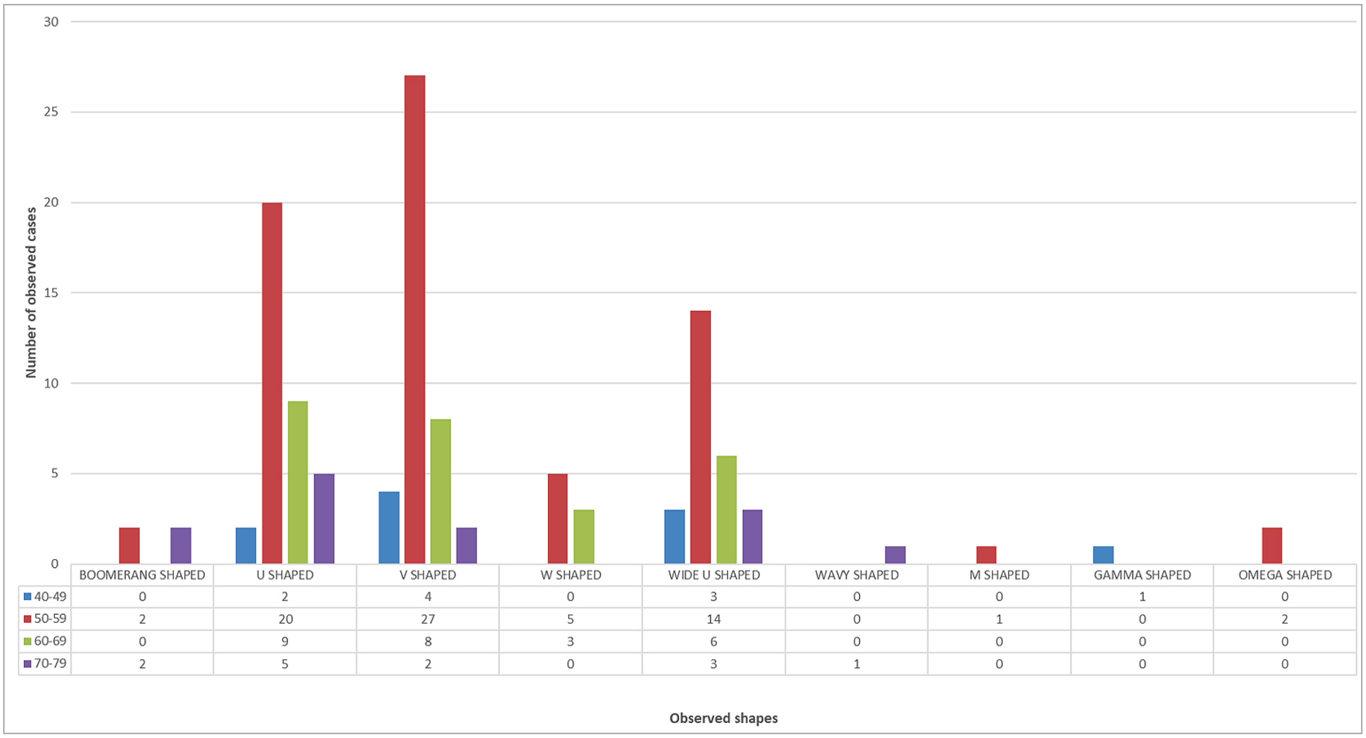

Figure 4. Distribution of different shapes and case numbers observed in the transverse colon.

A computer engineer (7 years experience) evaluated the images. For 160 patients, a dataset was created and labeled using the acquired images. The model was trained on the labeled images, and the model's performance was evaluated in terms of accuracy and other metrics.

The dataset required to train the model was obtained from 3D colon images of patients. There were 41 images from different angles for each patient. Of these images, 343 were obtained by taking at least two images from each patient. The data set consists of 343 images. Colon shapes close to each other are divided into four groups: (i) U, wide-U, and V shapes are group I, (ii) M and W shapes are group II, (iii) omega and boomerang shapes are group III, and (iv) typical images are group IV. Each image was converted to 640x640 pixels and was labeled by the radiologist and the anatomist. The RoboFlow application was used to annotate each image in YOLO format. The dataset was randomly divided into 70:20:10 partitions for training, validation, and testing. The dataset groups and sample numbers used in the training and testing of artificial intelligence are as follows: Train group 240 samples (Group 1, n= 145; Group 2, n= 52; Group 3, n= 12; Group 4, n= 31), Valid group 68 samples (Group 1, n= 49; Group 2, n= 11; Group 3, n= 1; Group 4, n= 6) and Test group (Group 1, n= 19; Group 2, n= 9; Group 3, n= 1; Group 4, n= 6).

Deep learning methods like YOLOv8 are very computationally demanding. This means that they require high-performance hardware. Google Colab was used in this study to overcome this problem. Google Colab is a notebook where Google servers perform high computations. Google Colab also provided the libraries needed for this study. The analysis of the dataset was performed on a Tesla Graphics Processing Unit (GPU-T4, 15102 MiB) using the Ultralytics YOLOv8.0.203 library and the Python-3.10.12 programming language running on the Google Colab platform using torch-2.0.1+cu118.

The parameters and values used in object recognition are as follows: 640x640 image size, Volov8x model, epochs of 100, 2 batches, SGD as an optimizer, Ir0 and Irf values of 0.01, momentum 0.937 and weight decay was 0.0005.

Statistical analysis

All data were analyzed using a statistical package program (SPSS version 18.0; SPSS, Inc., Chicago, IL, USA). The variables were investigated using visual (histograms, probability plots) and analytical methods to determine whether they were normally or not normally distributed (using Kolmogorov-Smirnov and Shapiro-Wilk tests). Due to the nonparametric distribution of the data, the Mann-Whitney U test was used to compare the colonic annular lengths and the intergroup (such as gender, tortuosity, etc.) in the comparison of paired groups, and the Kruskal-Wallis test in the presence of more than two groups. Spearman correlation test was used in correlation analysis, and the chi-square test was used to evaluate categorical data. A 5% type-1 error level was used to infer statistical significance ($p < 0.05$).

Ethics approval

The study protocol was approved by the medical faculty's non-interventional clinical research ethics committee (approval number: 2023.79.04.15, date: 25/04/2023).

Results

Statistical analysis results

The mean age of 89 men and 71 women included in the study was 57.8 ±8.55 and 56.6 ±6.61, respectively, and there was no statistically significant difference (*p*= 0.24).

In our study, the total length of the large intestine of all cases (n= 160) was 163.05 ±24.05, caecum and ascending colon 27.76 ±6.84, transverse colon 46.63 ±10.21, descending colon 39.96 ±8.01, sigmoid colon 38.32 ±13.65 and rectum 10.38 ±4.39. The total large intestine length was 166.51 ±25.2 cm for men and 158.73 ±21.92 cm for women; no statistically significant difference was observed between groups (*p*= 0.12).

The large intestine was divided into the proximal part (from the caecum to the splenic flexure) and the distal part (from the splenic flexure to the rectum). While there was no statistical difference in the proximal colon in the comparison between the sexes (72.43 ±12.80 cm and 76.86 ±13.50 cm, respectively, *p*= 0.069), the distal colon length was found to be higher in men than in women (94.09 ±17.64 cm, 81.87 ±13.36 cm, respectively, *p* <0.001).

Table 1. The summary of morphological differences seen in some cases (given as mm)

	n	Min	Max	Mean	SD
Transvers Colon Ptosis	103	21.30	191.00	105.34	34.16
Transverse Colon Elevation	25	19.80	108.50	67.16	26.84
Wide U-Shaped Transverse Colon Width	26	21.50	109.50	62.80	25.70
Transverse Colon Upward Convexity	17	31.20	97.60	60.83	21.09
Cecal Shift	20	19.20	159.70	77.45	33.34
Caecum Midline Lateral Shift	15	10.00	105.20	37.93	29.68
Caecal Elevation	6	12.00	148.40	74.08	48.47
Flexural Eventration	123	14.50	132.60	55.18	25.10

(n: sample size, min: minmum, max: maximum, SD: standart deviation)

Table 2. The lengths of the total large intestine and its segments according to the gender **(given as cm)**

	Male (n= 89)				Female (n= 71)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Total Large Intestine	122	254	166.51	25.21	108	223	158.73	21.92
Rectum	5	27	10.23	4.81	6	26	10.57	3.83
Sigmoid Colon	14	97	41.36	14.43	9	63	34.52	11.64
Descending Colon	26	65	42.51	7.94	20	50	36.77	6.91
Transverse Colon	24	77	44.96	10.42	25	88	48.73	9.62
Caecum + Ascending Colon	7	42	27.47	5.65	17	64	28.12	8.13

Table 3. The lengths of the total large intestine and its segments according to the age groups (given as cm)

	40-49 (n= 10)	50-59 (n= 97)	60-69 (n= 37)	70-79 (n= 16)
Total Large Intestine	166.1 ±14.58	160.41 ±23.55	168.43 ±25.3	164.75 ±28.13
Rectum	9.1 ±2.88	10.09 ±4.37	10.91 ±4.57	11.68 ±4.78
Sigmoid Colon	39.80 ± 9.72	36.98±12.0	40.9 ±14.45	39.62 ±21.57
Descending Colon	45.0 ±11.25	39.30 ±7.12	41.21 ±7.78	37.93 ±10.3
Transverse Colon	42.8 ±9.26	46.58 ±10.56	47.78 ±10.16	46.68 ±8.96
Caecum + Ascending Colon	29.4 ±5.4	27.47 ±6.83	27.62 ±5.52	28.81 ±10.22

The morphometric features of the large intestine segments and colonic types are provided in Supplementary Figure 1S and Tables 1, 2 and 3.

Transverse colonic ptosis was found in 49 male patients (31.0% on the right, 51.0% in the middle, and 18.0% on the left) and 54 female cases (14.8% on the right, 64.8% in the middle, and 20.4% on the left). When transverse colon ptosis was compared according to gender, no significant difference was found in right-sided (male, 91.78 ±21.72, n=15; female, 109.76 ±36.81, n= 8; p= 0.107), midline (male, 100.56 ±29.43, n= 25; female, 117.55 ±34.60, n= 35; p= 0.107) and left-sided ptosis (male, 88.84 ±40.85, n= 9; female, 106.17 ±41.12, n= 11; p= 0.184), but a significant difference was observed in total ptosis heights between the two genders (male, 95.70 ±29.57, n= 49; female, 114.08 ±35.90, n= 54; p= 0.013).

Transverse colon elevation was observed in 25 cases (19 cases in the middle, one on the mid-left, and five on the left). The elevation of the cases in the middle part was calculated as 72.55 ±26.68 mm, those in the middle left were 46.2 mm, and the cases on the left were 50.88 ±27.89 mm.

AI results

In the artificial intelligence part of this study, the YOLOv8 object detection system was used to estimate the shape of 3D colon images. In this study, IoU≥0.5 was used to measure the intersection between the predicted and real masks. In addition, the metrics used to measure the accuracy of the models were recall, precision and mAP50 (Figure 5).

The YOLOv8x model was trained on the generated data series, and the training results are shown in Supplementary Figure 2S. The model took 51 minutes to train. Precision and recall started to converge after about 80 epochs, and precision was above 80% after 100 epochs. The PR curve for the validation dataset is shown in Figure 5(A), with an average precision of 91.4% for all categories and a peak precision of 99.5% for a single category.

The evaluation of the YOLOv8 model using key metrics such as Precision, Recall, and mAP50 is given in Figure 5(B). After 100 Epochs, Precision is 0.8578, Recall is 0.7940 and mAP is 0.9142. Figure 5(B) shows that the model is slowly improving. However, from time to time, it is seen that the model suddenly drops to the worst training scores of the metrics.

The performance of the model was also evaluated with a test dataset. The test dataset corresponds to 10% of the entire dataset and consists of 35 images, which is different from the images the model failed to match during training and validation. Of the predictions made by the model on the 35 images, 31 were correct (88.6%). When the incorrect prediction images are analyzed, they are seen as similar to the predicted group. Supplementary Figure 2S shows some of the predictions made on the test dataset.

Discussion

Computed tomography colonography is the radiological procedure of choice when endoscopic evaluation of the colon is problematic or impossible. This approach is safer than endoscopic inspection because it is performed without anesthesia and avoids potential problems.

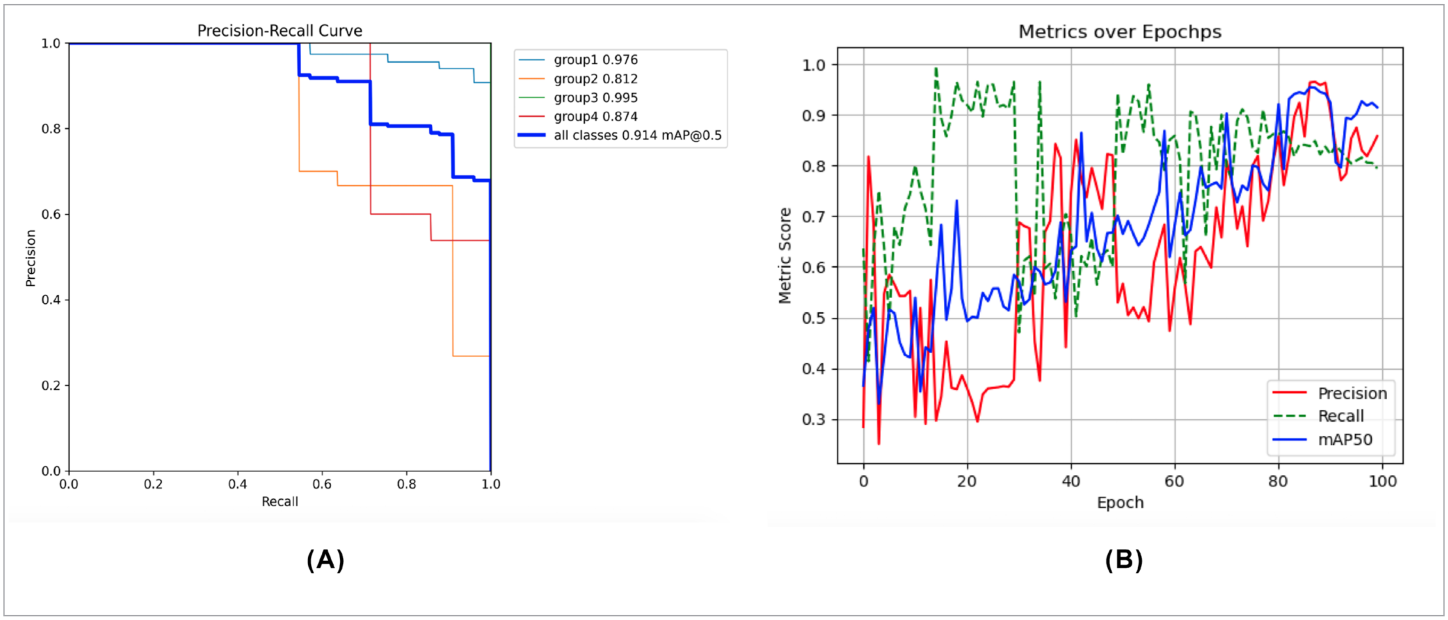

Figure 5. (A) PR Curve, (B) Evaluation of the YOLOv8 model using key metrics such as Precision, Recall and mAP50.

Furthermore, information on the complicated morphology of the colon is provided, providing the necessary knowledge for both acute interventions and later interventional processes [12,13].

Information on colon morphology has been studied in detail with cadaver studies [14]and colonoscopy studies [15]. However, variations and morphological differences that may interfere with colonoscopy may vary between individuals. Acute angulations observed in the colon are called tortuosity, and their frequency according to age and sex has not yet been studied to the best of our knowledge. Our study studied the tortuosity of the colon in male and female patients of different ages, which was examined by CT colonography, and its relationship with segmental morphology was revealed. In addition, transverse column tortuosity typing was performed, and the incidence rates were given in the study.

While previous studies have found total colon length to be greater in women [16-18], the men included in this study had higher colon length. However, the observed difference did not show any statistical significance. In women, tortuosity was more common distal to the colon. It has been reported that adult women complain of constipation more than men, and it has been reported to be associated with gynecologic surgery [19]. Utano et al. [18] have associated constipation in women with proximal colon length. However, unlike their study, it can be suggested that it may be related to the fact that tortuosity is higher in distal colonic segments compared to men. Worldwide, colorectal cancer incidence and mortality rates are higher in men [20].

The large intestine's main functions involve accumulating digestion residue and absorbing water and electrolytes. The ascending and transverse colon sections contribute significantly to this process. With gravity, feces positioned in the lumen of these regions exert a downward effect. While this is accommodated by expansion in the caecum, positioned at the base of the ascending colon, it might cause the transverse colon to curve downwards because it is in the horizontal plane. Furthermore, because the greater omentum is attached to the transverse colon, it is thought that the fat deposition that happens here due to weight increase may result in downward pulling in the transverse colon. As a result, ptosis in the transverse column can be seen in varying degrees and numbers [21].

During the embryological development of the intestine, significant changes occur in its morphology due to its rotations and contact with the posterior abdominal wall (ascending and descending colon parts). Secondarily, retroperitoneal parts and intraperitoneal transitions (flexures) and parts of the mesostructures that allow movement significantly affect the morphology of the colon. Secondarily, retroperitoneal parts that are less mobile are structurally less tortuous, while intraperitoneal parts that are more mobile are expected to be more [22].

The transverse colon is the section of the large intestine that is approximately 50 cm long and transverse in the abdomen, which is connected between the ascending and the patterned colon and connected to them by colic flexures. The transverse column has greater mobility than other segments of the colon. The length of the peritoneal structure called the transverse mesocolon, which attaches to the posterior abdominal wall, may be variable. The length of the transverse mesocolon and the position of the colic flexures and their angulation can cause variations in the shape and position of the transverse column [23]. Causes of transverse colon variations include clinical conditions such as congenital abnormalities, genetic predisposition, gender, fiber-deprived diet, prolonged straining, and irritable bowel syndrome. Transverse colon length can cause bowel problems, nausea or skin problems that manifest with symptoms such as constipation and abdominal pain (excessively long bowel, redundant colon) [24].

The use of artificial intelligence models for morphometric detection and clinical diagnosis support has been increasing recently. In our study, object detection of the shape of the transverse colon of the large intestine was performed with YOLOv8. It is predicted that the data obtained in this way will make an important contribution to morphological definitions related to the transverse colon.

The limitations of the study are that the study is retrospective, and there was no detailed clinical and laboratory information on the patients due to the use of an online dataset. In addition, improving the limited data set will improve the results of AI and machine learning.

Conclusion

This article highlights the importance of understanding the morphology of the large intestine for accurate interpretation of CT colonography results and effective clinical management of patients with suspected large intestine abnormalities.

In addition, this study suggests that the tortuosity and length of the colonic segments in each patient may be variable. It has been revealed that the length of the distal colon is longer for male gender compared to females. This information is important for performing interventional procedures such as conventional colonoscopy in the elderly. It has been shown that CT colonography is important in the typing of tortuosity, and it should be kept in mind that the transverse and sigmoid colonic segments have more tortuosity. Furthermore, this study showed that 88.57% of the images in the test data set were detected correctly and that AI can play an important role in colon typing.

[3]Data Availability: United States National Cancer Institute (https://www.cancerimagingarchive.net/)

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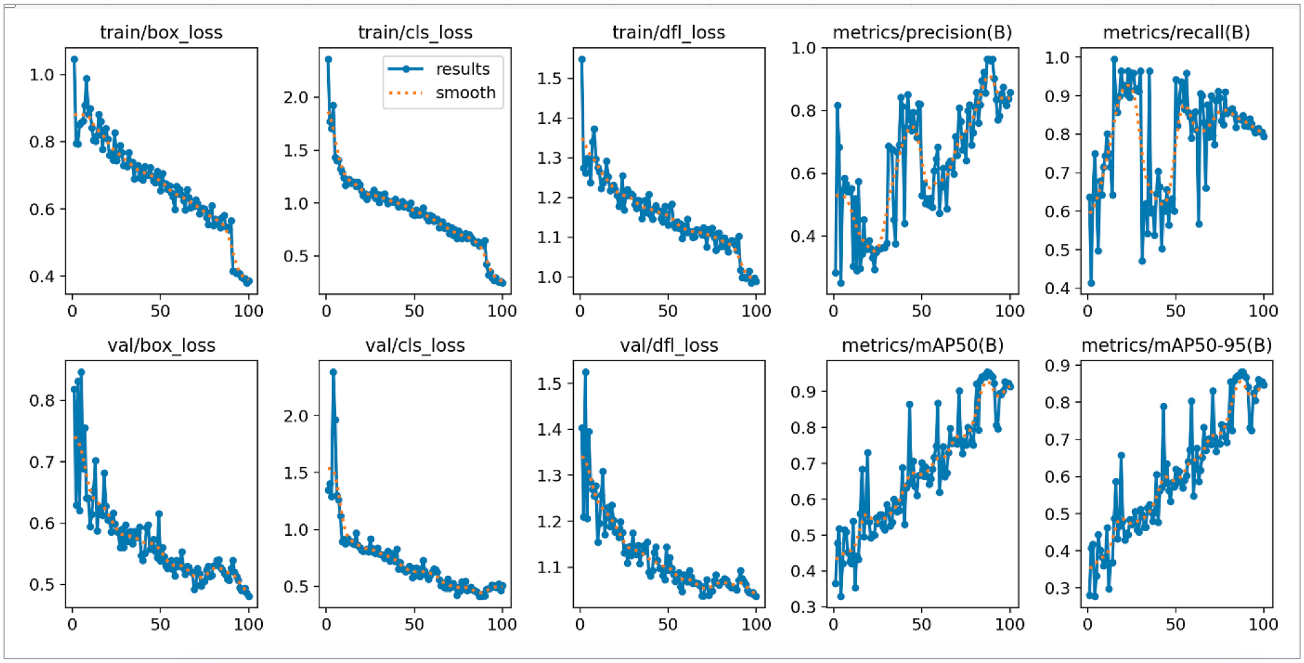
Supplementary

Figure 1S



Training results of the YOLOv8x model.

Figure 2S