"COMPARISON OF MANNITOL, WATER AND IODINE BASED ORAL CONTRAST IN EVALUATION OF BOWEL BY MULTIDETECTOR COMPUTED TOMOGRAPHY"

By

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DISSERTATION SUBMITTED TO SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND RESEARCH, KOLAR, KARNATAKA

In partial fulfilment of the requirements for the degree of

DOCTOR OF MEDICINE
IN
RADIODIAGNOSIS

Under the Guidance of

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DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation entitled **"COMPARISON OF MANNITOL, WATER AND IODINE BASED ORAL CONTRAST IN EVALUATION OF BOWEL BY MULTIDETECTOR COMPUTED TOMOGRAPHY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. N. RACHEGOWDA**, Professor & Head, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, and co-guidance of and **Dr. A. NABAKUMAR SINGH,** Associate Professor, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, in partial fulfilment of University regulation for the award "**M. D. DEGREE IN RADIODIAGNOSIS**", the examination to be held in April/May 2020 by SDUAHER. This has not been submitted by me previously for the award of any degree or diploma from the university or any other university.

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Dr. Thati Sai Soumya

LIST OF ABBREVIATIONS

3D – Three dimensional

AEC – Automated exposure control

ANOVA – Analysis of variance

CECT – Contrast enhanced computed tomography

CO_2- Carbon dioxide

CT - Computed tomography

CXR – Chest radiograph

D – Duodenum

EBCT - Electron beam computed tomography

GIT - Gastrointestinal Tract

HU – Hounsfield Unit

I1 – ileal site 1

I2 – ileal site 2

ICJ- Ileocaecal Junction

IMA – Inferior mesenteric artery

IV – Intravenous

IVC – Inferior Vena Cava

J1 – Jejunal site 1

J2 – Jejunal site 2

Kg – Kilogram

kVp – Kilo-voltage peak

L - litre

mAs- Milli ampere second

MDCT - Multi-Detector Computed Tomography

mL- millilitre

MPR – Multi-planar reconstruction

MR – Magnetic resonance (imaging)

NS- Normal saline

PIC – Positive iodinated contrast

RFT – Renal function test

LIST OF ABBREVIATIONS

SBFT - Small bowel follow through

SD – Standard deviation

SMA - Superior Mesenteric Artery

ABSTRACT

Background: Mannitol has high osmolarity and therefore it is hypothesized to provide better distension of bowel loops.

Objectives: The aims and objectives of the study were to perform contrast enhanced CT abdomen (CECT) with water, mannitol and iodinated positive contrast as oral contrast agent and to compare the distension and enhancement pattern of bowel with water, mannitol and positive iodinated contrast on CECT abdomen.

Material and methods: This was a prospective observational study conducted on 90 patients over a period of 12 months (December 2018 to November 2019) who were referred for CECT abdomen. Patients were randomly divided into three groups (30 each) and were given water, mannitol and positive oral contrast before the CECT study. Quantitative and qualitative analysis of the bowel for distension, mural fold pattern, enhancement and image quality was analyzed by diameter measurement and point scale system at various anatomical levels, which included duodenum, jejunum, ileum and ileocecal junction. Qualitative examination of bowel loops was done in the three groups by using a continuous 4-point scale.

Results: Out of 90 cases, there were total 45 males and 45 females with no significant difference between gender distribution across the three groups. The mean distension at duodenum was 1.89 ± 0.33 cm (mean ± SD) with water, 2.28 ± 0.36 cm (mean ± SD) with mannitol, and 2.01 ± 0.33 cm (mean ± SD) with positive oral contrast. Overall,

maximum luminal distension was seen at the level of duodenum followed by jejunum across all the groups . The least luminal distension was seen at the level of ileocecal junction across all subgroups. Bowel distention and various mural characteristics were of far superior in the mannitol group compared to water and positive oral contrast at all anatomical levels including duodenum, ileum, jejunum and ileo-caecal junction. Wall enhancement was better appreciated with mannitol compared to other two contrast agents.

Conclusion: Small bowel distension was excellent with mannitol followed by positive oral contrast and least by water. Mural characteristics and enhancement pattern were better with mannitol as compared with water and positive oral contrast. We recommend that mannitol should be employed on routine basis for CECT abdomen study.

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INTRODUCTION

Small bowel is a challenging area for the surgeon and the gastroenterologist because of its long length and vague symptomatology, often making the radiologist an essential part of the diagnostic team[1]. Ultrasound is less sensitive for evaluating bowel due to bowel gas artifacts. Computed tomography (CT) has good spatial and contrast resolution and is considered a better modality for the evaluation of bowel pathologies[2].

Small bowel remains a difficult site to interpret, owing to its anatomy and varied imaging appearances[1]. Since radiologists assume primary responsibility in the diagnostic evaluation of the small bowel, it is essential that methods capable of accurately demonstrating small bowel morphology are appropriately applied. Barium investigations are helpful in detecting intraluminal pathologies, but are often non-specific with low diagnostic yield[2]. Small bowel capsule endoscopy is a recent imaging modality for small intestinal pathologies, but due to its inability to evaluate extramural pathologies, capsule retention in luminal stenosis and diverticula, its application is restricted[2]. Conventional abdominal CT can depict extramural pathologies but usually overlooks the intraluminal and intramural diseases. Multi-detector computed tomography (MDCT) with optimal enteral contrast agent has overcome the above-mentioned limitations and has revolutionized the exploration of bowel[3].

Mannitol has high osmolarity and therefore it is hypothesized to provide better distension of bowel loops[4]. There is paucity of data on what actually constitutes an ideal oral contrast agent. This study was taken up to demonstrate if bowel distension and enhancement

pattern on MDCT is better visualised with mannitol in comparison with water and iodinated oral contrast, thus helping in optimal bowel evaluation.

AIMS AND OBJECTIVES

Aims and objectives of the study were:

1. To perform contrast enhanced CT abdomen (CECT) with water, mannitol and iodinated positive contrast as oral contrast agent.
2. To compare the distension and enhancement pattern of bowel with water, mannitol and iodinated contrast on CECT abdomen.

REVIEW OF LITERATURE

EMBRYOLOGY

There are three germ layers formed during gastrulation, which include endoderm, mesoderm and ectoderm. Endoderm gives rise to epithelial lining and glands. The mesoderm forms the lamina propria, muscularis mucosae, submucosa, muscularis externa and serosa. The ectoderm predominantly gives rise to the enteric nervous system[5].

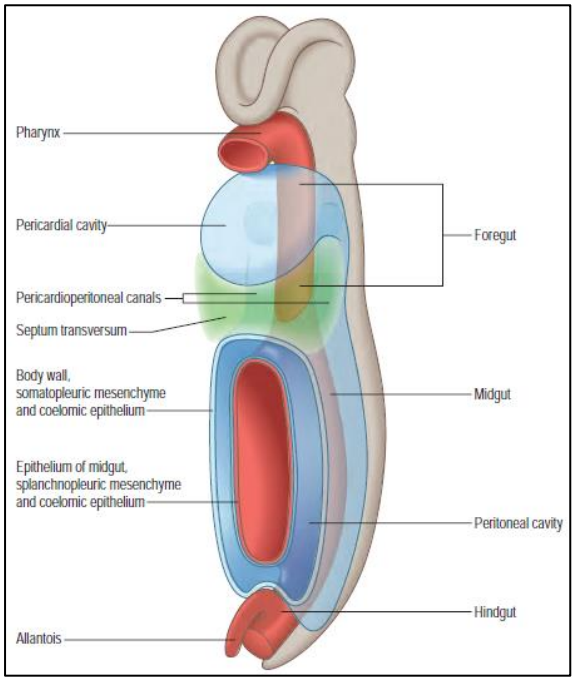

Figure 1. Early embryonic period.

Table 1 Derivatives of germ layers

Endoderm	Epithelial glands and lining
Mesoderm	Lamina propria , muscularis mucosae, submucosa, muscularis externa and serosa
Ectoderm	Enteric nervous system and posterior luminal digestive structures

The primitive gut tube develops during third to fourth week of embryonic life by incorporating the yolk sac during craniocaudal and lateral folding of the early embryo. The tube is divided into 3 different sections; foregut, midgut and hindgut (Figure 1and Figure 2). Foregut gives rise to esophagus, stomach, liver, gallbladder, bile ducts, pancreas and proximal duodenum. The midgut develops into the distal duodenum, jejunum, ileum, cecum, appendix, ascending colon, and proximal 2/3rd of transverse colon. The hindgut forms the distal 1/3rd of the transverse colon, descending colon, sigmoid colon and the upper anal canal[6].

In 6th week there is obliteration gut lumen due to epithelial proliferation of the gut tube (Figure 3). Eventually there is degeneration of central cells and recanalization of the tubes occurs by 8th week. Abnormalities in this process result in bowel atresia, stenosis and duplications[7].

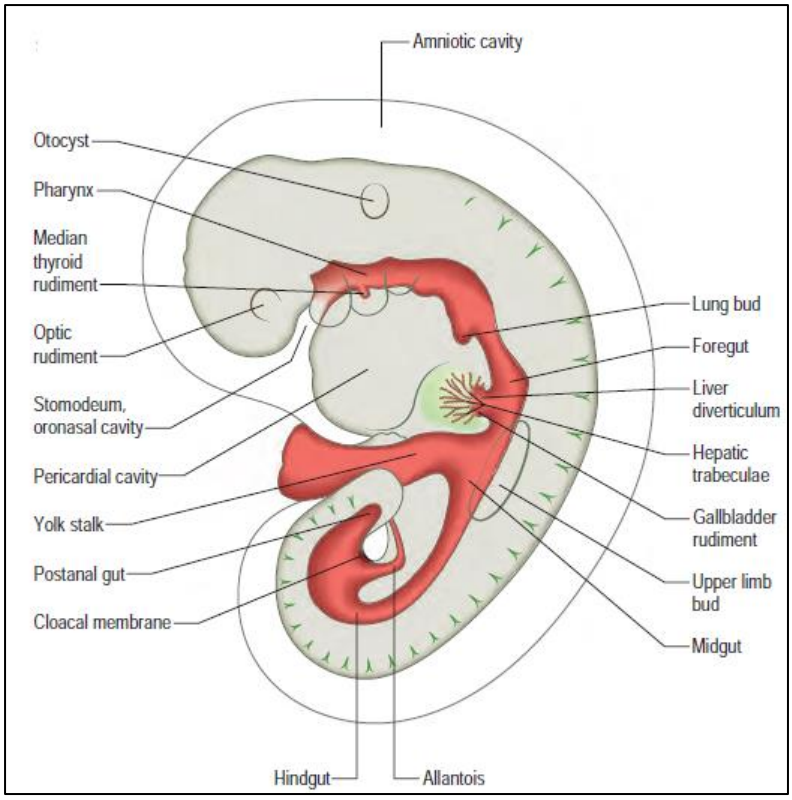

Figure 2. Illustration showing the digestive tube of a human embryo at a crown to rump length of 3.4 mm and an estimated age of 27 days.

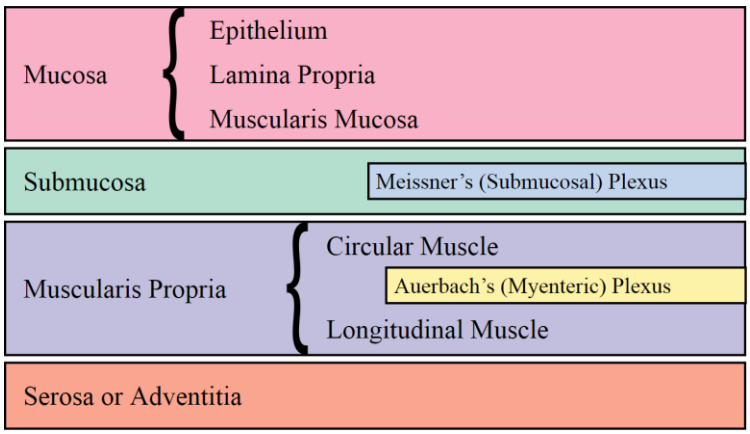

Figure 3. General organization of the gastrointestinal tract.

Derivatives of Foregut:

The foregut gives rise to the esophagus, stomach, liver, gallbladder, pancreas and the upper portion of the duodenum.

Oesophagus

It elongates during various stages and its absolute length increases more rapidly in comparison to the embryonic growth. Cranially, it is limited by splanchnopleuric mesenchyme and it lies posterior to the trachea. Caudally, it lies between the developing lungs and pericardioperitoneal membranes[8].

Stomach

At around fourth to fifth weeks, the stomach can be identified as a fusiform dilation superior to the communication of the midgut with the yolk sac

Figure 4). By fifth week, this opening is narrowed into a tubular vitelline duct, which soon loses its connection with the intestinal tube and hence becomes a vestigial structure. At this time, the stomach is median in position and separated superiorly from the pericardium by the anatomical septum transversum. A ninety-degree rotation in clockwise direction results in the formation of lesser peritoneal sac[8].

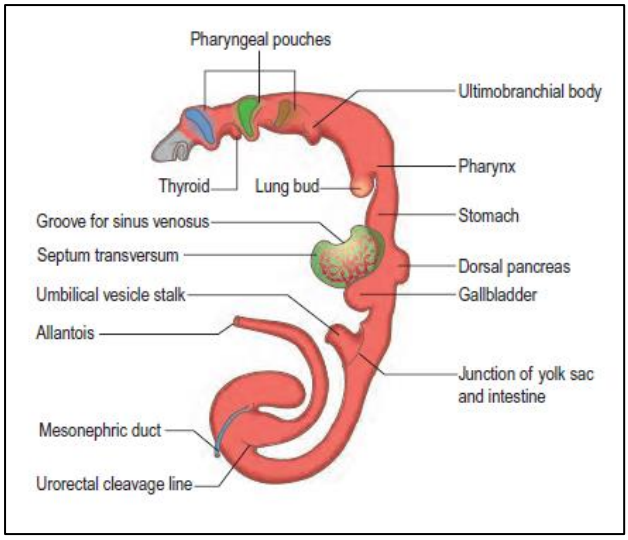

Figure 4 Development of the gut.

Proximal or upper duodenum

Arises from the inferior most part of the foregut and is supplied by anterior and posterior branches of the superior pancreaticoduodenal artery, which is a direct branch of the celiac axis. During rotation of the gut tube, the duodenum and pancreas are pushed up against the body wall and becomes retroperitoneal[8].

Derivatives of the Midgut

Distal or lower duodenum

The cranial most part of the midgut gives rise to distal duodenum and is supplied by the inferior pancreaticoduodenal artery, which is a branch of the superior mesentery artery.

Like the rest of the duodenum, it becomes secondarily retroperitoneal. Similar to the entire gastrointestinal tract, there is transient obliteration during development and then recanalization of the lumen. Failure of recanalization can result in atresia (complete blockage) or stenosis (narrowing). Such patients present with bilious projectile vomiting after feeds[9,10].

Jejunum, ileum, cecum, appendix, ascending colon, and proximal two thirds of transverse colon

The tube rapidly elongates, overwhelming the capacity of the embryonic abdominal cavity and forming a U-shaped loop that herniates from the umbilicus and gets oriented along the axis of the embryo. Eventually there is an upper or cranial loop and a caudal loop. The upper loop contains the future jejunum and proximal part of ileum. The lower, or caudal loop, contains what will form the lower ileum, cecum, appendix, ascending colon and proximal 2/3 of the transverse colon. The appendix is seen as a diverticulum that is first pointed downwards or caudally. The midpoint of the loop of the future ileum is attached to an elongated remnant of the yolk sac called ‘the vitelline duct’ that eventually becomes obliterated[8].

Failure to obliterate the vitelline duct can result in outpouchings called the Meckel's diverticula, vitelline cysts or vitelline fistulas (a connection of the small intestine to the skin). These structures will have one attachment to umbilicus and the other end to the ileum[8].

In the later sequence of events, the gut tube undergoes a primary rotation of 90 degrees in anti-clockwise such that the caudal loop containing the appendix is on the embryo's left side. As the embryo grows, the abdominal cavity expands and thus draws the tube back into the abdominal cavity, during which time the gut tube rotates another 180 degrees further such that the appendix finally assumes its normal position in the upper right quadrant. The gradual growth of colon pushes the appendix down to the lower right quadrant its final location[11].

Failure of the gut contents to return to the abdominal cavity results in defects like omphalocele.Variations or defects in rotation can cause a variety of aberrant anatomical positions of the viscera that are often asymptomatic, but important to appreciate when trying to diagnose and/or treat gastrointestinal problems e.g. abnormal or atypical positioning of the appendix.Malrotation can also cause twisting or midgut volvulus, resulting in ischemia or stenosis of the bowel[11].

ANATOMY

The small intestine forms an important component of the gastrointestinal system. The mean diameter of small bowel is < 2.5 cm and they can distend upto a calibre of 4 cm. It measures ~ 6 meters in average length, extending from duodenum to ileocecal junction and comprises duodenum, jejunum and ileum (Figure 5). It receives the undigested or partially digested food from the stomach, mixes it with fluid from the biliary system namely bile and

pancreatic juices, aids in the digestion, absorption of nutrients and conveys this mixture to the ascending colon[4].

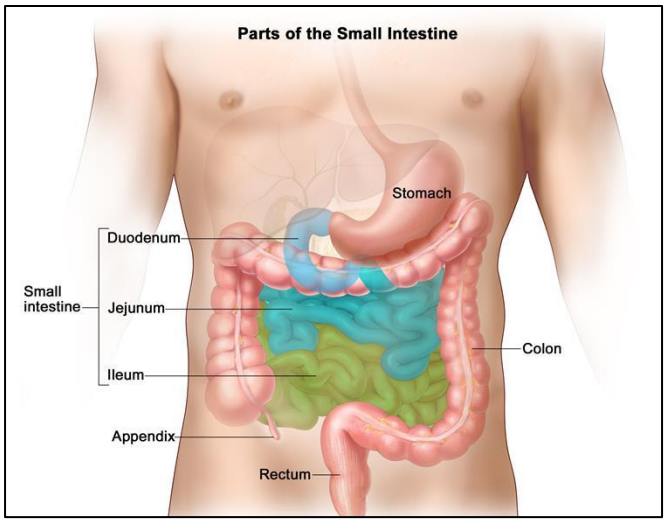

Figure 5. Parts of small intestine

Duodenum

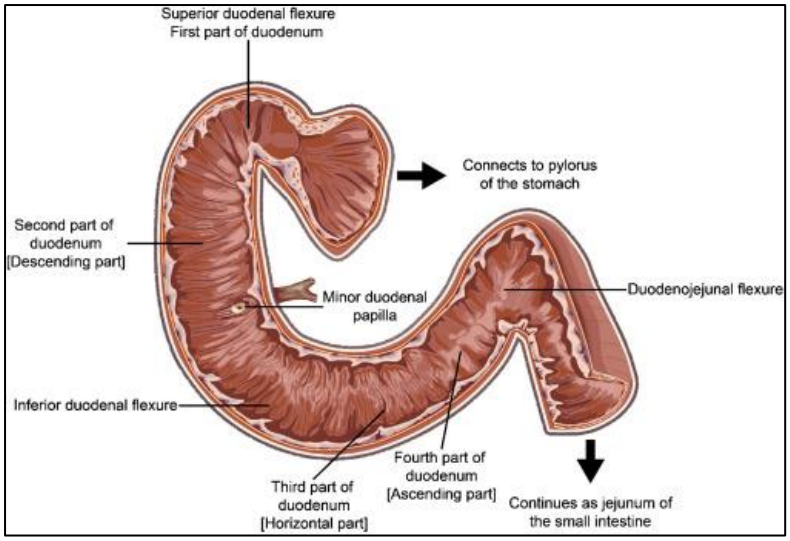

Figure 6 Parts of the duodenum

The literal meaning of the word ‘duodenum’ is “two plus ten,” as the length of this part of the small bowel is almost equivalent to 12 fingers’ breadth. The duodenum is a C-shaped hollow viscerum lying in close proximity to head of pancreas. lt is 25 cm lengthwise and connects the stomach to the jejunum. Its location being both retroperitoneal and intraperitoneal. Its proximity to the gallbladder, pancreas, stomach, spine, aorta and liver, results in duodenal involvement by a myriad of pathological processes. lt is divided into four distinct parts (Figure 6) as follows: the first (superior), the second (descending), the third (horizontal) and the fourth (ascending) parts. Peritoneum covers the proximal 2 cm of the duodenum on both sides. The remainder of the distal part of the duodenum is retroperitoneal[12].

The duodenal cap or bulb represent the first 2 cm of the duodenum, has a mucosal pattern showing resemblance to the stomach. These thin mucosal folds are lost or effaced by distension, resulting in the so called smooth, featureless pattern. The remainder of the duodenal mucosa is thrown into many circular folds[12].

The first part of the duodenum originates at the pylorus and descends to the right, posteriorly and superiorly on the right crus of diaphragm to the medial border of the right kidney. The first 2-3 cm of the duodenum is intraperitoneal. Anteriorly it is related to the gallbladder and the hepatic parenchyma. Posteriorly, the inferior vena cava and common bile duct are located. Superiorly, it is related to the epiploic foramen and inferiorly it is related to pancreatic head[12].

The second part of the duodenum passes downwards from the superior duodenal flexure in anterior relation to the hilum of the right kidney; the anterior aspect of the hepatic flexure of the colon is closely related to its anterior surface. The ampulla of Vater is guarded by a semi-lunar shaped fold of mucosa which opens into the descending duodenum along its posteromedial wall[13].

The third part of the duodenum courses forward over the right psoas muscle and then crosses the inferior vena cava (IVC) and aorta to the left psoas muscle, thereby passing anterior to the mesentery of the small bowel. It is also called as inferior or horizontal part of the duodenum and it begins at the inferior duodenal flexure and passes transversely to the left, crossing the midline and hence the vertebral column. Anteriorly, it is related to the root of the small bowel mesentery. Posteriorly, it is related to the right psoas muscle, right ureter, aorta, IVC and gonadal vessels. The pancreatic head lies superior and the jejunal loops lie inferior to the third part of duodenum[13].

The fourth part of the duodenum, also known as the ascending part courses superiorly, either anterior or to the right of the abdominal aorta upto the inferior border of pancreatic body. Then, it courses anteriorly and ends at the duodenojejunal flexure where it merges with the jejunum. A muscle fibre containing peritoneal fold surrounds the duodenojejunal flexure - the ligament of Treitz. The fourth part of the duodenum is superiorly related to the stomach, inferiorly it is related to the loops of jejunum. Left psoas muscle and aorta lie in its posterior relation[13].

Functional Anatomy of Gastrointestinal Tract

The small bowel has an enormous absorptive surface area of about 300 m^2. This large absorptive area helps in optimal and effective absorption of nutrients and other materials from food. The reason behind such a large absorptive area is the presence of unique mucosal structure arranged in concentric folds, which appear as transverse ridges. These are also referred to as plicae circulares and are about 2 inches long and 3 mm thick[14]. These folds are not lost during physiological distension of bowel unlike the rugae in stomach, which are lost when stomach distends. These folds can cover half to two-thirds of luminal circumference or may have more than one turn. They can be either horizontal or oblique in presentation[15]. These circular folds are seen maximum distal to major duodenal papilla and in proximal half of jejunum and reduce in size and frequency as one traverses bowel distally to ileum. These folds are almost completely absent in distal ileum and therefore this segment of bowel is thin. These folds increase absorptive area and also reduce the time taken for passage of contents[15]. It is believed that small intestine contains nearly 800 plicae circulares, which increase the mucosal surface area by 5 to 8 times more compared with outer surface area[14].

The entire mucosa of small bowel contains small projections referred to as villi, which further increase the surface area of intestinal lumen and also give a velvety texture of mucosa. Similar to mucosal folds, the villi are numerous and tall in duodenum and jejunum and reduce as one traverses distally and are short and fewer in number in ileum[15].

The variable number of plicae circulares and villi result in different rate of absorption in intestines. There are various specialized cells and receptors in particular sites, which explain the variable absorption at different sites. For example, iron and calcium are selectively absorbed in duodenum and proximal jejunum[8]. The presence of specialized cells and receptors in small intestine also ensure that maximum nutrient transport. Meanwhile, large colon is primarily responsible for water and electrolyte exchange. It is estimated that gastrointestinal tract (GIT) handles nearly 8 to 10 L of fluid of which only 1.5 L is left for colonic absorption, while the rest of water and electrolyte absorption is handled by small bowel. The bulk of pancreatic, biliary, intestinal and salivary secretions are also absorbed by the small bowel[16].

Jejunal anatomy

The outer diameter of jejunum is almost 4 cm and an inner diameter of about 3 cm. The jejunum has avid arterial supply and its wall is thicker than ileum. The plicae circulares also called as Kerckring folds are complex mucosal folds of the small bowel predominantly seen in the beginning of jejunum. The jejunal folds commonly branch upon each other giving them the peculiar appearance during barium studies, CT or magnetic resonance (MR) enterography[15]. The plicae circulares can also be seen by capsule endoscopy, which is a newer technique which transmits images of the small bowel wirelessly from a small camera of the size of a pill which is swallowed. When gastric emptying is defective, food is delivered directly into the duodenum/jejunum via a nasal transpyloric Ryle's tube or nasogastric tube. On supine imaging, the jejunum is situated in the upper abdomen, to the left of the midline in the infracolic compartment, whereas the ileal loops lie in the lower right part of the abdomen.

This distribution is distorted and may be reversed in small bowel obstruction due to twisting of the dilated bowel around the attachment of its mesentery[15].

Ileum

The ileum has a median outer diameter of about 3 cm, an inner diameter of about 2.5 cm and commonly has a thinner wall as compared to the jejunum. The plicae circulares in the distal ileum are less in number and flatter. The mucosa of the terminal ileal loops in the immediate vicinity of ileocaecal junction appear almost flat on endoscopic examination, although the villi can be seen when viewed in magnified images. In the supine position, the ileum lies predominantly in the hypogastric region and right iliac fossa[17]. The terminal ileum frequently lies in the pelvis, from where it ascends over the right psoas major and right iliac vessels, to end by opening at the ileocaecal junction in the right iliac fossa[15].

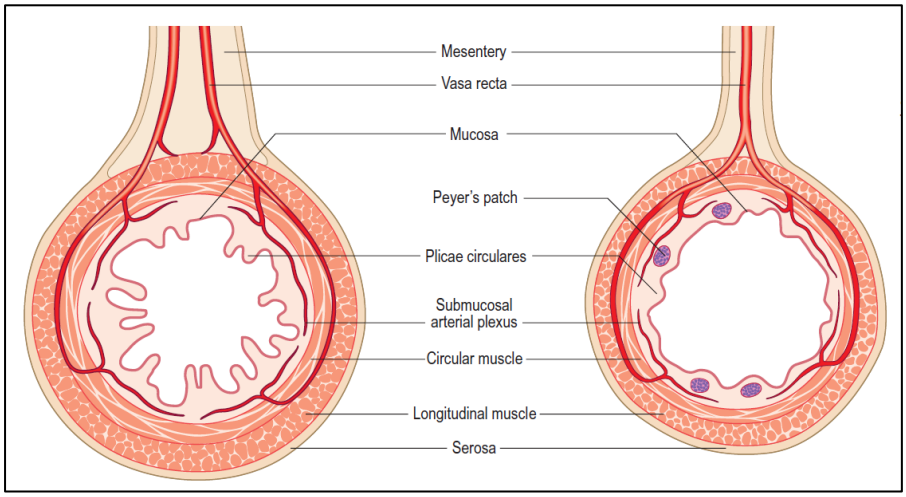

Figure 7. Layers of jejunum (left) and ileum (right).

Differences between ileum and jejunum

The jejunum and the ileum have no clear distinction. However, there are subtle general anatomical differences. The jejunum wall is thicker and has more vascularity, a greater number of prominent plicae circulares. The average length of the small bowel, measured from the duodenojejunal flexure to the caecum or ileocaecal junction is approximately 5 m but can range from 3 to 8.5 m. Males have lengthier small intestines than females, and height is proportionally related to the small bowel length[18].

After surgical resection, the remainder of the small bowel undergoes an adaptive process that involves incorporation of various morphological and functional changes. There is small bowel dilatation and increase in the villus height and crypt depth, causing expansion of the absorptive surface area. Soon after the intestinal resection, adaptation begins and it may last upto 2 years[19]. However, there are differences between the ability of the proximal and distal small bowel to adapt; the likelihood of regaining intestinal autonomy is greater in patients with a segment of ileal loop which is retained, with colon in continuity, as compared to patients with a residual jejunal segment and an end-jejunostomy[20].

There are also differences between the mesenteric vessels in the jejunum and ileum[21]. The jejunal mesentery which extends from the superior mesenteric artery to the mesenteric border of the small bowel. The jejunal mesentery is shorter than the ileal mesentery, and the jejunal arteries are marginally larger than their ileal branches (Figure 7). The jejunum typically contains 1–3 layers of vascular arcades, on the other hand there are often 2–6 layers

in the ileum. The arteriae recta in the ileum are more in number, shorter and narrower than in the jejunal counterparts (Table 2). The ileal, jejunal arteries and arteriae recta are muscular arteries capable of producing significant changes in the splanchnic blood flow, which can vary between 10% - 35% of cardiac output. Solitary lymphoid follicles, which are most numerous in the distal ileum are scattered throughout the small intestinal mucosa[21].

Aggregated lymphoid follicles which are also called as Peyer's patches, are circular or oval masses containing 5–260 follicles. They are rarely present in the duodenum as small, circular, few in number and also in the distal jejunum which are not palpable; and larger, more numerous and often palpable in the ileum, more so in the terminal 25 cm of ileum[22]. Lymphoid aggregates are most prominent in early childhood and, when enlarged in viral infections, they form the apex or a lead point for an intussusception. They become less prominent around puberty, and decrease further in number during adult life[22].

Table 2. Anatomical Differences Between Jejunum and Ileum

Jejunum	Ileum
Located in upper left quadrant	Located in lower right quadrant
Thick intestinal wall	Thin intestinal wall
Longer vasa recta (straight arteries)	Shorter vasa recta
Less arcades (arterial loops)	More arcades

Meckel's diverticulum

A congenital ileal diverticulum called Meckel's diverticulum is found in 2–3% of individuals and it is known to be the remnant of vitellointestinal duct (proximal portion). It grows from the anti-mesenteric border of the terminal ileal loops and is found around about 50 and 100 cm from the ileocaecal junction. It usually measures approximately 2-5 cm and contains a mesentery which is short in length, having adipose tissue and a vitellointestinal artery and extends from the mesentery to its base (Figure 8). Rarer complications of a Meckel's diverticulum include intestinal obstruction, intussusception, perforation, calculi and tumours[23].

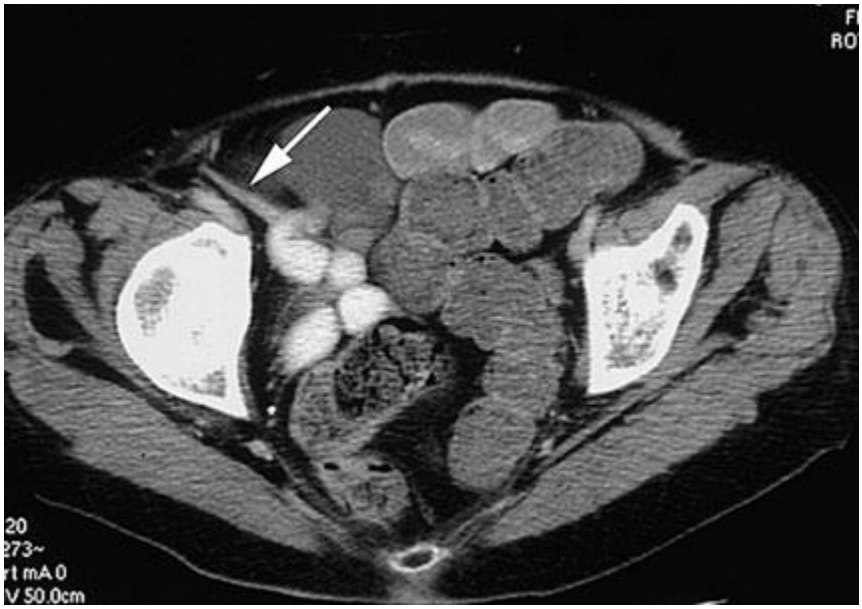

Figure 8. CECT abdomen axial section showing Meckel's diverticulum containing positive oral contrast

Intestinal length changes with neuromuscular tone and vascular flow and is extremely variable. For example, an intestine without a vascular supply or innervation appears stretched at autopsy varying from 10 to 30 feet[24].

Another method of classifying the small bowel is as the mesenteric small intestine which is further divided into the jejunum and ileum. The jejunum consists of the proximal 40% and the ileum comprises the distal 60% The jejunum typically occupies the left upper quadrant, and the ileum occupies the pelvis and right lower quadrant. The location of the jejunum and ileum is often variable; however, it is mobile owing to the suspension at the root of the mesentery and frequently the jejunal loops flop into the right upper quadrant or change position during fluoroscopic examination of the small bowel[3].

The mesenteric small intestine has a smooth curvilinear outer contour. The inner margins of the small intestine are made of folds that encircle the lumen, known as the plicae circulares or folds of Kerckring or valvulae conniventes (Figure 9). These folds are comprised by mucosa and submucosa and they cause resultant 300% increase in the surface area of the small intestine. The small bowel folds lie perpendicular to the longitudinal axis of the intestine. Villi are leaf- or finger-shaped protrusions of epithelium and lamina propria that line the surface of the folds at regular intervals. Each villus contains lamina propria containing a cellular stroma, capillaries, a lacteal, and nerves (Figure 9). Villi are longer and thinner in the jejunum as compared to the ileum. Duodenal villi are short and broad, leaf-shaped, branched or Y shaped and show highly variable anatomy. The villi are approximately about one mm in cross section and they just about meet the limits of fluoroscopic resolution. The microvillous brush border is invisible on all radiological examinations (Figure 10).When neutral contrast agent is used, the intestinal lining and mesenteric vessels can be delineated[15] (Figure 11).

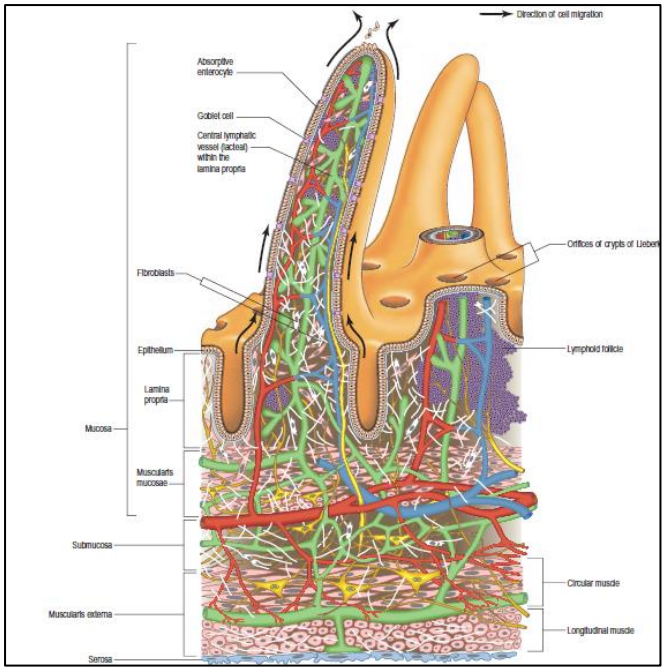

Figure 9 Architecture of an intestinal villus[15]

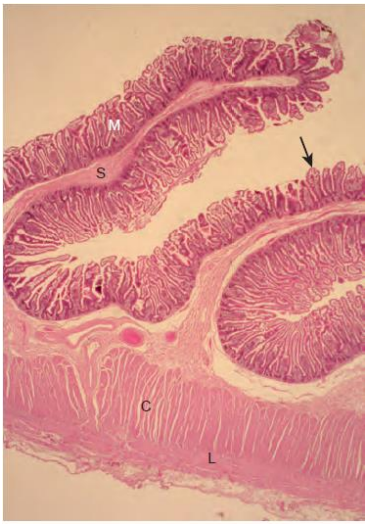

Figure 10 Histologic photomicrograph showing two small bowel folds. Each fold or plica is composed of a mucosal layer (M) composed of epithelium, lamina propria, and muscularis mucosae covering a central submucosal core (S). Each villus (arrow) is comprises a single layer of epithelial cells covering a central core of made up of lamina propria. The muscularis propria is composed of an inner circular muscle layer (C) and outer longitudinal muscle layer (L).

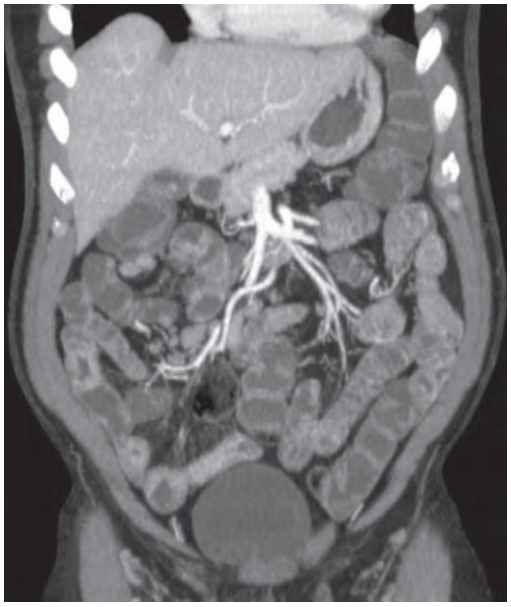

Figure 11. CECT abdomen coronal reformatted image showing distended bowel loops (filled with neutral contrast) and mesenteric vessels.

Ascending Colon

The caecum and vermiform appendix are radiologically important components of the ascending colon. The vermiform appendix arises as a small diverticulum from the antimesenteric border of the inferior limb of the midgut loop. The caecum does not possess a primitive mesocaecum. These regions undergo long periods of growth and show various types of variant anatomy. The vermiform appendix is covered with visceral peritoneum in its entirety, derived from the diverging layers of its so called mesoappendix. The mesoappendix should be regarded as a direct derivative of the (primitive) dorsal mesentery, and so are the vascular fold of the caecum. The colon retains its embryonic dorsal mesentery, the mesocolon, until the differential growth, rotation and circumabdominal displacement of this part of the gut tube near completion. The original root persists vertical in the dorsal midline,

although the mesocolon divides from it as an incomplete, flattened pyramidal structure, to reach its colonic border at the future so called taenia mesocolica[15].

Ileocaecal Junction

The ileocaecal valve is the separation of the small intestine and large intestine. Its function is to prevent the reflux on enteric fluid from the colon into the small intestine. It is used as an identification point in colonoscopy, and indicates that the limit of the colon has been reached and that a complete colonoscopy has been performed[25].

The ileocaecal valve is also important in the setting of large bowel obstruction. Should the ileocaecal valve be competent, a closed loop obstruction can occur and threaten caecal perforation. Should the ileocaecal valve be incompetent (i.e. allow backflow of enteric contents into the small bowel) then the situation is less emergent and the trajectory of the obstruction less rapid[25].

The terminal ileum joins the posteromedial aspect of the large intestine at the caecal colonic junction, where it protrudes into the lumen of the large bowel as the ileal papilla (Figure 12). It consists of two labial folds i.e. upper and lower. Its shape and anatomy varies from a linear slit-like structure to an oval mucosal rosette, partly depending on the state of contraction or distension of the caecum. At their bases labial fusion occurs and they continue as narrow mucosal ridges called frenula[25].

The ileal papilla is formed by the mucosa, submucosa and external muscle layers of the ileum, in continuity with the wall of the colon and combining with layers from the caecum inferiorly and the colon superiorly. A focal muscular thickening at the base of the ileal papilla indicates the presence of an intrinsic anatomical sphincter. The bilabial configuration of the papilla may be responsible for its valvular function. The ileocolic junction has several functions: it provides relative mechanical and functional separation of the luminal environments of the small and large bowel, which differ in their composition, pH and bacterial content; it prevents the reflux from the colon; and it helps in the regulation of antegrade small bowel transit[25].

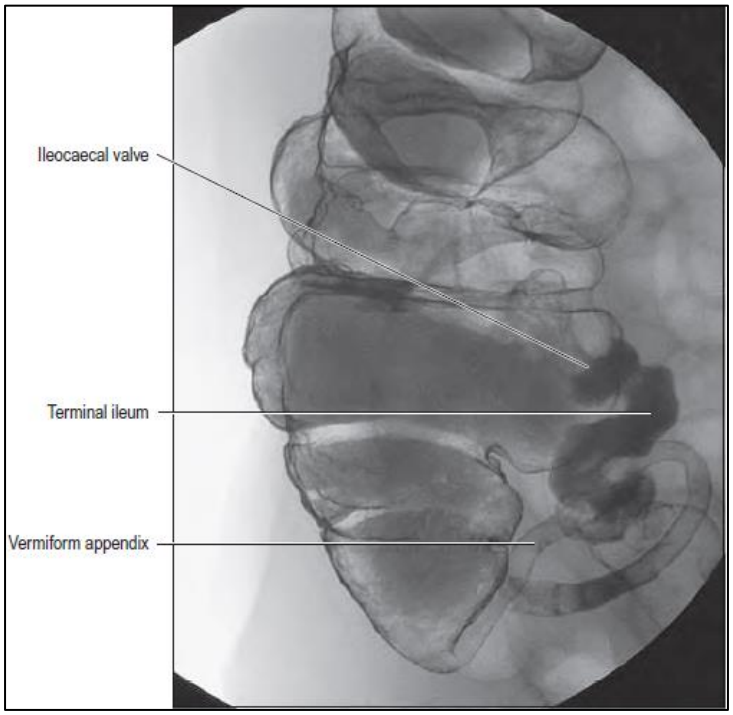

Figure 12 The caecum and ileocolic junction, double contrast barium enema appearance[24].

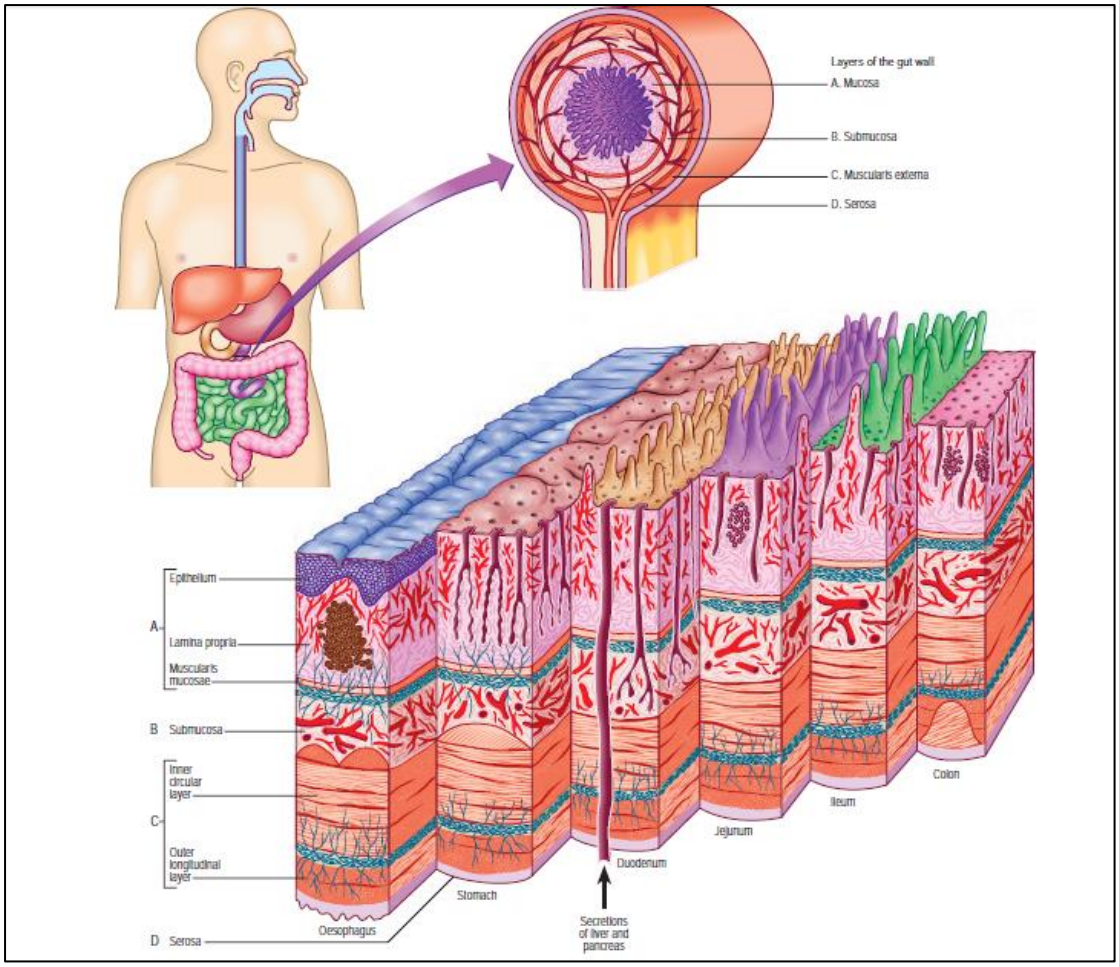

Figure 13 Arrangement of layers of gastrointestinal tract.

Layers of Bowel Wall

The mature gut wall is composed of four main layers: mucosa, submucosa, muscularis externa and serosa (Figure 13)[24].The mucosa is the most internal layer and is further divided into an epithelium, a layer of loose connective tissue called lamina propria where there are numerous glands. The muscularis mucosae is a very thin layer which is mainly composed of smooth muscle. The strongest layer of connective tissue is submucosa which is also shows high vascularity. The next layer, namely the muscularis externa comprises smooth muscles out of which the inner layers are arranged in circular form and outer layers are arrange in

longitudinal fashion. The external surface is bounded by a serosa or adventitia, depending on its location[24].

Vascular plexuses

Vascular plexuses are predominantly present in the submucosa and mucosa. They connect with vasculature that supply the adjacent tissues and those entering through the mesentery, and accompany the ducts of overlying glands[24].

Blood supply

Table 3. Blood Supply of Small and Large Bowel Loops[15]

Segment	Blood supply
Duodenum	Superior and inferior pancreaticoduodenal arcade
Jejunum	Jejunal branches from SMA
Ileum	Ileal branches from SMA
Caecum	Branches of SMA – anterior and posterior caecal arteries
Large bowel – ascending colon and proximal transverse colon Descending colon	Branches of SMA – Right and middle colic artery Left colic artery -IMA
IMA – inferior mesenteric artery; SMA – superior mesenteric artery	

The blood supply to the duodenum is by the superior and inferior pancreaticoduodenal arcade; the first 2 cm is supplied by the right gastric, right gastro-epiploic and gastro-

duodenal arteries. In short, proximal to the major duodenal papilla – the duodenum is supplied by the gastroduodenal artery which is a branch of the coeliac trunk and distal to the major duodenal papilla it is supplied by the inferior pancreaticoduodenal artery a branch from the superior mesenteric artery. The jejunum, ileum, ascending colon and, usually right half of the transverse colon is supplied by the superior mesenteric artery. The descending colon and sigmoid colon are supplied by inferior mesenteric artery[26] (Table 3).

INVESTIGATIONS

Plain radiograph

Historically, an erect abdominal radiograph was performed as an additional modality for the acute abdomen in order to assess the number and length of any fluid levels within bowel. This was thought to distinguish between obstruction and ileus. However, this distinction is highly unreliable, and evidence shows that the erect abdominal radiograph can be misleading. The erect chest radiograph (CXR) appearances can be inconclusive when looking for free peritoneal gas. Occasionally, a left lateral decubitus radiograph can provide some information, since small amounts of gas can be seen over the liver if there has been a perforation[27].

In the acute abdominal setting, plain radiography should be asked for in situations where it is likely to yield useful information. Plain radiography is useful in diagnosing perforation of a viscus, and for assessing bowel. It is not helpful in diagnosing the common causes of acute abdomen such as appendicitis, diverticulitis, cholecystitis and pancreatitis.

For this reason, plain radiography should be avoided in these situations except when there is suspicion of perforation or bowel dilatation[27].

Plain abdominal radiograph is often the first line of investigation in evaluation of bowel despite the availability of other advanced imaging modalities. The calibre of the small and large bowel loops can be studied on a routine plain abdominal radiograph. In cases of small bowel obstruction, the findings on plain radiograph are dilated loops of small bowel, measuring more than 30 mm proximally and 25 mm more distally. Air fluid levels greater than 25 mm in length are abnormal, air fluid levels at various different positions within the same loop, the 'step ladder' pattern and small bubbles trapped between dilated loops-the 'string of pearls sign' are the signs that indicate small bowel obstruction[27].

Intramural gas (pneumatosis intestinalis), pneumobilia and portal venous gas also can be diagnosed on plain radiograph. Another important radiographic diagnosis is that of hollow viscus perforation in which there is presence of free intra-peritoneal air on a plain abdominal radiograph[28].

Bowel dilatation occurs in a number of conditions due to mechanical intestinal obstruction, paralytic ileus and also due to air swallowing. The radiological differentiation of various causes depends on clinical correlation and the calibre and distribution of various bowel loops[28].

Distinction between Small and Large-Bowel Dilatation

When a radiograph shows dilated bowel, it is important to try to determine whether it is small or large bowel, or both depending on the size and distribution of the loops. Distended small-bowel loops are usually more numerous and arranged centrally in the abdomen. The normal calibre of the bowel is around 2.5 cm. The small-bowel folds called valvulae conniventes form thin, circumferential bands across the bowel shadow, prominent in the jejunum but are almost completely absent in the ileum. The valvulae conniventes are much closely packed together as compared to the haustrae of the colon. In case of compromised blood supply of the small bowel the valvulae conniventes becomes oedematous and thickened[27]. Frequently, it is difficult to distinguish between the distal ileum and the sigmoid colon as both sometimes have smooth outline and assume a similar position in the lower abdomen. Haustra are not always a consistent feature of the large bowel as they may be absent in the descending and sigmoid colon. but can sometimes still be identified in rest of the large bowel, even when it is grossly distended[28].

Ultrasound

Although ultrasound lacks the effect of ionising radiation, its capacity of diagnosing small bowel pathologies is dependent on multitude of factors like patient body habitus and bowel preparation of the patient. It is an excellent modality when it comes to assessment of real time peristalsis, calibre and anatomy of various bowel loops[24].

Barium studies of the small bowel:

Almost 9 litre of fluid is received by small intestine each day, out of which only 1.5 to 1.9 L enters the large bowel. Because of the native length and inherent motility of the small intestine, imaging of the same can take a long time. With peristalsis, intestinal loops overlap with changes in size, shape, and position. The normal small bowel transit time is around 30 to 120 minutes. The transit time can be more in patients with features of obstruction or adynamic ileus from various causes[24].

Evaluation of the luminal contour and search for abnormalities that extend beyond the small intestine (e.g., diverticula, sacculations, ulcers, exoenteric masses) or lesions that protrude into the lumen can be possible with barium studies. The small bowel folds are best evaluated when the lumen is in fully distended state. The folds usually are perpendicular to the longitudinal axis of the small bowel. Fold width is inversely proportional to the degree of luminal distention. Hence, greater the distention, the thinner the folds appear. One of the disadvantages of barium are that if folds are evaluated after the passage of barium column, the incoming intestinal secretions can elevate the barium away from the mucosal surface and can give an appearance of erroneously thickened folds[24].

Evaluation of mucosal details are important for detecting mucosal pathology such as granularity or nodularity or small ulcers like aphthoid ulcers. The head of the barium column is examined to understand the course and complexity of the small intestine and to detect

contour abnormalities or filling defects in the barium column. Bowel motility, distensibility, and pliability can also be assessed during the fluoroscopic examination[24].

Small Bowel Follow-Through

A small bowel follow-through (SBFT) is an examination of the small intestine that uses single-contrast medium like barium (30-50% weight by volume) which is given in large volume. Initially, the upper gastrointestinal tract is evaluated as a prelude to the examination.

After the esophagus, stomach, and duodenum are evaluated, the patient leaves the fluoroscopic room and slowly consumes an additional quantity of barium. A small bowel follow-through evaluation is done by spot films which are taken at certain intervals when each segment is optimally distended with the barium column. The time duration of the entire examination depends on the pace of the barium column in the intestine. The patient is turned into various positions (including supine, lateral, and prone compression views) and various manoeuvres are used to cause splaying out of small bowel loops for better evaluation[24].

The length of the study can be reduced by administering a standard dose of 20 mg of metoclopramide orally or intravenously before the examination. Metoclopramide improves the small bowel transit and accelerates gastric emptying. Sometimes, few doses of effervescent agent (600-900 mL of carbon dioxide) can be administered when the barium column reaches pelvic loops of ileum or the terminal ileum. However, administration of an effervescent agent is uncomfortable as large volume of gas can produce severe intestinal cramping. It also results in decreased luminal distention in comparison to CT abdomen

studies using neutral contrast agent. Two important limitations of small bowel follow-through are that there is delayed pyloric emptying of barium resulting in the incomplete distention of small bowel loops. Another limitation is long duration of the examination due to varied normal small bowel transit time (30 to 120 minutes) and also intermittent evaluation of the small bowel[24].

Peroral Pneumocolon

A peroral pneumocolon may be performed in association with a small bowel follow-through and is mainly used for evaluation of the terminal ileum, ileo-caecal junction and in the diagnosis of suspected Crohn's disease[29]. In some cases where colonoscopy fails to visualise the aforementioned areas, peroral pneumocolon comes into picture[29].

The patient undergoes a barium enema first. One milligram of intravenous glucagon is administered and air is administered into the rectum via a catheter after routine small bowel follow-through. The goal is to create a double contrast study (contrast and gas) of the ascending colon and terminal ileum. This allows better assessment of the mucosa of particular segments of bowel, which may be important for evaluating conditions like inflammatory bowel disease[29].

Enteroclysis

The conventional fluoroscopic technique is not commonly used since it is invasive, time consuming, skill driven and unpleasant for the patient in question. With experience and

good technical skills, however, it is one of the best techniques for evaluation of the small bowel mucosa.

There are three types of enteroclysis, each having its own advantage and disadvantage. Single-contrast enteroclysis is a relatively easy technique causing less patient discomfort, but evaluation of the mucosa is less efficacious than the other techniques. For better evaluation of mucosal detail of small bowel loops air contrast enteroclysis can be used. However, there is more patient discomfort than single contrast. The last type is methylcellulose enteroclysis, which is better for short segment pathologies[24].

Parameter	Enteroclysis	Small Bowel Follow-Through
NUMBER OF FOLDS PER INCH		
Jejunum	Four to seven	Difficult to count
Ileum	Two to four (or less)	Difficult to count
FOLD THICKNESS (MM)		
Jejunum	1-2	2-3
Ileum	1-1.5	1-2
FOLD HEIGHT (MM)		
Jejunum	3-7	Difficult to assess
Ileum	1-3	Difficult to assess
LUMEN WIDTH (CM)		
Jejunum	<4 cm	<3
Ileum	<3	<2

Figure 14 Enteroclysis versus small bowel follow through[24].

Hypotonic Duodenography

Hypotonic duodenography is a study which comprises detailed examination of the duodenum and in some cases also the first two loops of jejunum. This examination is used when there are conflicting radiographic or endoscopic findings in the duodenum and first few loops of the jejunum[24]. Firstly, enteroclysis catheter is positioned in the second part of

duodenum and then high-density barium is administered. After barium passes through the duodenum and jejunal loops, the patient is mobilised into various positions on the fluoroscopic table to coat the maximum extent of visualised mucosa. Air is introduced into the catheter to dilate the duodenal lumen, and spot films are obtained. MR hypotonic duodenography is also a feasible technique, however it is expensive and time consuming[30].

Capsule Endoscopy

Capsule endoscopy is a relatively new, non-invasive diagnostic technique for evaluation of the small bowel. In this study a swallowable video capsule is used (Figure 15). The most common indication for capsule endoscopy is occult gastrointestinal bleeding, which commonly depicts small bowel pathologies and ulcers missed at standard imaging techniques and endoscopy[31].

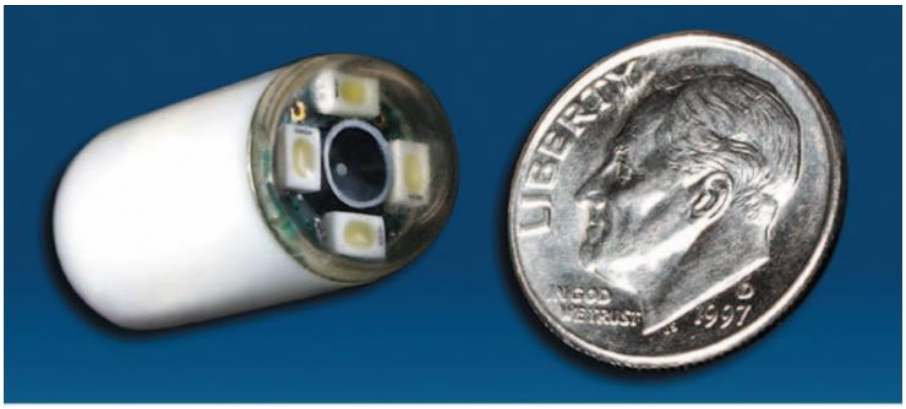

Figure 15 Capsule used in capsule endoscopy

Contraindications

A known case of small bowel stricture or bowel obstruction is an absolute contraindication for capsule endoscopy. Capsules that are not excreted naturally will require surgical removal. A pacemaker is a relative contraindication, as there is a risk of the capsule interference with pacemaker function[31].

Limitations

Lesions can be missed due to various factors such as small bowel transit time (rapid or slow), positioning of the camera and poor bowel preparation. Computed tomography overcomes these limitations and is useful for detecting these missed lesions and for localizing lesions detected at capsule endoscopy. Other limitations of capsule endoscopy are its limited use in patients with small bowel strictures or obstruction[31].

Complications

The total non-natural excretion rate is 0.75% based on more than 10,000 capsule endoscopic examinations. The video capsule endoscope was proven to be superior to radiographic examination for evaluation of small bowel[32].

CT IMAGING: BACKGROUND

There has been a significant improvement in the field of medical imaging in both the technologic and clinical areas following the discovery of X-ray in 1895 by Wilhelm Conrad Roentgen, a German Physicist. Innovations in technology are a norm in the Radiology domain, with introduction of new ideas and methods and refinements in existing techniques happening continuously. One such evolution is the invention of CT. The first idea of a computed tomography machine was conceived by Sir Godfrey Hounsfield in 1967 and the first patient was scanned for brain cyst in 1971[33].

Sir Godfrey Hounsfield, an electronic engineer working at the Central Research Laboratories of EMI in England commenced work on image reconstruction in 1968. His original apparatus consisted of a collimated isotope source mounted on a lathe bed. The objects examined were phantoms contained within a ten-inch water. The scan took nine days to complete because of the low intensity of the X-ray radiation source, and a further two and half hours to process the reading through a computer. The resulting image though of poor quality proved that the system worked. To provide sufficient intensity the equipment was modified by replacing the isotope with an industrial X-ray tube[33].

A prototype scanner was then developed and installed in Atkinson Morley Hospital in Wimbledon, England on 1st October 1971. The first patient scan was a 41-year-old female with suspected frontal lobe tumour, the tumour was clearly demonstrated on the scan[33]. Hounsfield and Ambrose presented their paper on CT to the annual congress of the British Institute of Radiology on 20th April 1972 to great acclaim. The first CT papers, by these

authors appeared in British Journal of Radiology in 1973. The invention of this technique resulted in the award of 1979 Nobel Prize in physiology and medicine to Sir G. N. Hounsfield, Central Research Lab., England (EMI), and A. N. Cormack of Physics Department, Tufts University, Massachusetts, U.S.A. Advanced Technological Developments. Over the last ten years, four different generations of CT scan equipment were produced. The most important improvements have been in the reduction in the single image generation time from five minutes to 2.5 seconds in the third and fourth generations scanners and an increase in spatial resolution and contrast[33]. The introduction of second-generation CT scanners further reduced the scan time from about six minutes to about two minutes. Late second-generation CT scanners with ≥ 20 detectors further reduced scanning time to about ≤ 20 seconds. This dramatically improved quality of body scans, which could not be performed previously within a breath hold. The third-generation scanners further reduced the scan time to 5 seconds or less, which has now further improved to about 0.33 seconds[34].

Slip Ring Scanners

There was no significant improvement in CT technology following fourth-generation CT scanners in late 1980's. The only limitation at that time was interscan delays. Following one 360^0 rotation, the cables connecting rotating components (x-ray tube and detectors) to the rest of the gantry required rotation to be stopped and reversed for next slice, all of which added time of scan. All these changed with application of low-voltage slip rings. Slip rings provide electricity to the rotating components without fixed connections (Figure 16). Slip rings made it possible for continuous rotation, thereby reducing scan time. This technology also paved the way for introduction of spiral/helical CT scans[34].

In the mid-1980s, another high-speed CT scanner was introduced, which was referred to as the Electron Beam CT (EBCT) scanner used for imaging cardiovascular system. In 1989, Dr. Willi Kalender introduced volume scanning by using spiral / helical CT scanners. In spiral/helical CT Scanners, a thin X-ray beam traces a path around the patient and scans a volume of the tissue. Recently, dual slice spiral /helical CT scanner and multislice CT scanners were introduced which mainly increase the speed and volume of scan. Volume CT scanning has resulted in a wide range of applications such as CT fluoroscopy, CT angiography, 3D Imaging and virtual reality imaging[34].

Figure 16 Slip-ring technology in Siemens Somatom Emotion CT scanner

Role of Computed tomography

In the current scenario computed tomography is one of the best modalities for evaluation of the bowel. There are many limitations with other modalities such as small-bowel follow-through and enteroclysis as these modalities provide indirect information about the bowel wall and surrounding structures such as mesentery and also the problems due to overlapping of small bowel loops[35]. To overcome the limitations of above-mentioned

techniques, CT enteroclysis, a technique combining the advantages of enteroclysis and CT, has been tested. Although the advantage of CT enteroclysis is excellent distention of the entire small bowel as well as optimal evaluation of the extent of extra-luminal pathologies, it has the major drawbacks of high radiation exposure and being invasive it is uncomfortable for the patient. Another limitation is rapid peristalsis at the site of pathology due to which subtle important findings may be missed. Currently, the availability of MDCT and 3D imaging have greatly increased the utility of CT for evaluation of bowel and adjacent structures. MDCT has advantages over classic helical CT in the imaging of the mesenteric vasculature and bowel as well[36].

Normal Bowel on CT

The normal bowel wall thickness on CT depends upon the degree of bowel distension and vary widely in the literature. After extensive literature survey, it is found that the small bowel wall should not be more than 3 mm even in cases where is there is good luminal distention, and the colonic wall can vary from 1- 2 mm[37].

In post contrast studies, the layer which enhances the most is the mucosa which appears distinct. Whereas, the submucosa is less perfused and is rarely seen as a separate structure on cross sectional imaging unless it is involved by pathological processes like oedema, haemorrhagic or fat infiltration. The best sequence to assess the bowel wall is the portal venous phase in which the bowel shows uniform contrast enhancement[37].

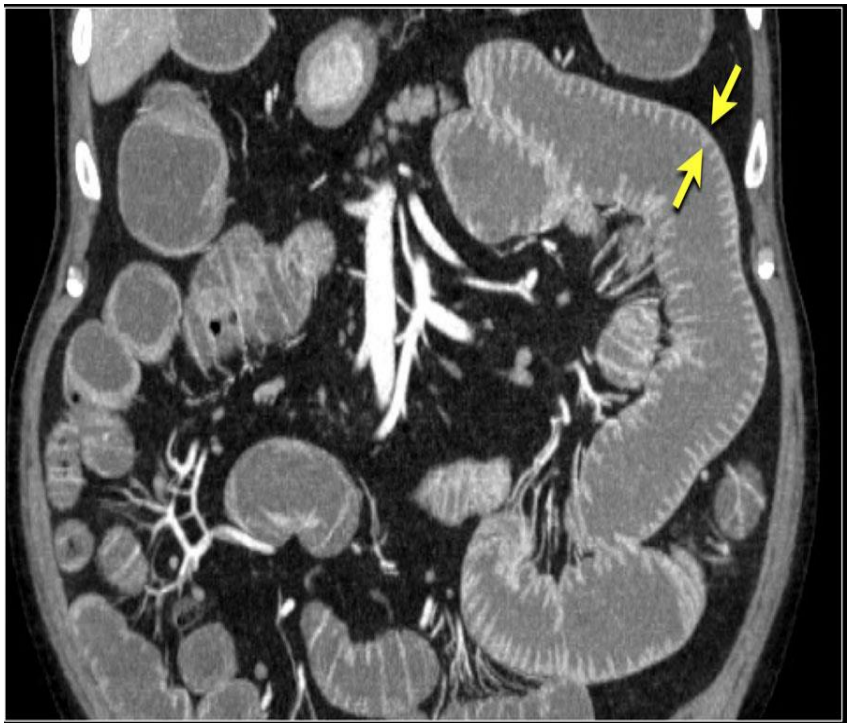

Figure 17 Normal bowel enhancement pattern

Attenuation Pattern of Bowel on CT

There are various types of attenuation patterns which include white, gray, water halo sign, fat halo sign, and black type. The white pattern is the avid contrast enhancement that uniformly affects most of the bowel wall. The bowel wall enhancement pattern is compared to the venous opacification in the same scan and if the enhancement is equal to or slightly greater than that of venous opacification it is classified in the white attenuation pattern. Common examples with this attenuation pattern include idiopathic inflammatory bowel diseases and vascular disorders like shock bowel, reperfusion after ischemia and haemorrhage. The gray pattern is defined as homogenously enhancing bowel wall whose attenuation is almost equal to that of enhanced muscle. This pattern is commonly used to differentiate between neoplastic and non-neoplastic aetiology, but is the least specific and

should be combined with other ancillary morphologic observations. Stratification within a thickened bowel wall that consists of either two or three contiguous, thickened layers (of equal thickness) is known as the water halo sign. This sign is seen in conditions like idiopathic inflammatory bowel diseases, infectious diseases and radiation damage[38].

The fat halo sign refers to a thickened bowel wall exhibiting three-layered target sign in which the middle "submucosal" layer has a fat attenuation. Basically, the target sign results from mucosal and serosal enhancement surrounding a thickened hypoattenuating submucosa. This sign is seen in conditions like Crohn disease and inflammatory bowel diseases of the colon. If the pathological segment of bowel exhibits a target appearance, it signifies the presence of ongoing benign process. Black attenuation signifies pneumatosis, commonly seen in ischemia, infection, and trauma[39].

Various bowel pathologies like tuberculosis, inflammatory bowel disease and their mural involvement can be diagnosed with greater sensitivity only if adequate bowel distension is achieved[4].

Patterns of Mural Enhancement

Target Appearance - Neutral contrast agent helps us to demonstrate the target sign better. It allows better characterisation of the inner aspect of the small bowel wall. The target sign was first described as a specific sign for Crohn's disease, but it can now be applied to

any non-neoplastic condition which may produce a target appearance on CT in the small bowel.

In patients with small-bowel thickening due to vasculitis, there is a combination of edema and haemorrhage in the wall secondary to the vasculitis-induced ischemia. Submucosal haemorrhage is known to cause homogeneous enhancement of the bowel wall after intravenous contrast administration. However, in special scenario where the contrast is administered as a rapid bolus intravenously, the small bowel usually shows a target appearance in the setting of submucosal haemorrhage. The main differential diagnosis of small-intestinal submucosal haemorrhage is intestinal ischemia. Both conditions are common in elderly patients. Majority of the patients with submucosal haemorrhage usually present with acute abdominal pain[39].

CECT abdomen is very useful in characterisation of skip lesions, transmural and mucosal changes, fat halo sign, comb sign, terminal ileal thickening and other extra-intestinal complications in cases of Crohn's disease[40]. Even though MRI has the advantage of high soft tissue resolution and non-ionising radiation, the disadvantages of MR imaging is that it is more time consuming, less readily available, and expensive. Advantages of CT over MR imaging include wider availability, faster examination times, the ability of CT to do various post data acquisition modifications with multi–detector row CT, and higher spatial resolution[40].

The most sensitive finding of active Crohn disease is mural enhancement. However, if the bowel loops do not show adequate distension, the collapsed bowel loops may mimic higher attenuation pattern in bowel loops. Inadequately distended bowel loops are difficult to assess, and other secondary signs of active disease, such as mesenteric fat stranding, vasa recta prominence, or extra intestinal complications such as fistulas and abscesses are better demonstrated if good distension of bowel loops is present[41].

Crohn's disease

A wide variety of diseases also cause hyperenhancement of the bowel wall; however, patchy and asymmetric hyperenhancement or linear hyperenhancement along the mesenteric border are pathognomonic for Crohn's disease[24]. Infection, backwash ileitis, angioedema (often from angiotensin-converting enzyme inhibitors), vasculitis, and bowel ischemia can all cause segmental hyperenhancement of bowel loops. However, these conditions are not usually associated with asymmetric enhancement or fistulous complications as seen in Crohn's disease. When equivocal hyperenhancement is seen, comparison of two nearby distended bowel loops and considering secondary signs of Crohn's disease are helpful. Radiation enteritis can show similar features like narrowed and hyperenhancing bowel loops, but it is easily distinguished from Crohn's disease because of the history of radiation and symmetric hyperenhancement[4].

Tuberculosis

Tuberculosis may involve any gastrointestinal tract segment, but it predominantly involves the ileocecal valve, terminal ileum and cecum which occurs in more than 90% of intestinal tuberculosis cases. Therefore, in the gastrointestinal tract, the terminal ileum and the ileocecal regions are the most commonly affected (50%). Hence to study these regions adequate bowel distension is important[42].

Primary Gastrointestinal Lymphoma

Another pathology which has predilection to a segment of the small bowel is lymphoma. The distal ileum is the most common site of small bowel lymphoma (B cell) as it contains more lymphoid tissue. On imaging, it is seen as circumferential mural mass often extending to adjacent small bowel mesentery. Long segment involvement of the bowel is seen which may ulcerate and project into the adjacent mesentery causing the formation of a localised sterile abscess. The lumen of the involved segment of the bowel shows aneurysmal dilatation. The etiopathogenesis is due to replacement of the muscularis propria and damage of the nerve plexus, predominantly autonomic. Since lymphoma lacks desmoplastic response bowel obstruction is not common[43].

Most Crohn's lesions favour the ileum, while ulcerative colitis affect colon predominantly involving the terminal ileum. Celiac disease affects the jejunum while the ileum was the site of predilection in lymphoma[44].

Conventional CT versus CT with oral contrast agents

CT with enteral contrast agent provides clear visualisation of the small bowel anatomy including lumen, mural characteristics, perienteric and extraenteric tissues by distending the small bowel with adequate volumes of oral contrast and subjecting the patient to undergo multiplanar CT imaging in enteric phase of the contrast study, which is usually the venous phase. It is different from the conventional CT with respect to the amount and type of oral contrast given to the patient prior to scanning, timing of acquisition of appropriate images and with respect to the intravenous (IV) contrast bolus administration, reconstruction of thin multiplanar images, and other patient-specific indications (e.g., Crohn's disease or , tuberculosis or obscure gastrointestinal bleeding).For CT Enterography, 1500- 2000 mL of oral contrast is typically administered to the patient over an hour in divided volumes[24].

Oral Contrast Agents and their Mechanism of Action with Pharmacoradiology

Classification of oral contrast agents:

When the small bowel is distended with oral contrast material, the wall appears thin and usually measures less than or equal to 2 mm. A major disadvantage of positive oral contrast in small bowel evaluation is that the density of luminal contrast and mucosal enhancement remains almost the same due to which there is no clear delineation of the mucosal enhancement pattern which serves as an important factor in the differential diagnosis

of an abnormal small-bowel. On the other hand, neutral oral contrast agents allow clear visualization of the intestinal wall, thereby allowing analysis of the pattern of small-bowel mucosal enhancement[39]

Neutral contrast agents are agents that have a CT attenuation value equal or close to that of water (10–30 HU). They must be used with intra-venous contrast material and the small-bowel distension must be adequate for the visualisation of the pathologies. Several neutral agents have been evaluated for small-bowel distension, including water, water in combination with an agent such as methylcellulose, polyethylene glycol solutions, and a commercially available low-density barium solution (VoLumen [low-Hounsfield-value barium sulfate]) and osmotic diuretics like mannitol[4].

The most commonly and widely available neutral contrast agent is water and it has a few disadvantages. It is rapidly absorbed from the gastrointestinal tract and hence it results in inadequate distension. Polyethylene glycol and VoLumen solutions are absorbed slowly Studies show that they are better than plain water in causing small-bowel distention[4].

CT enterography differs from CT enteroclysis in that enteroclysis is performed after placement of a nasojejunal tube. However, since it is non-invasive and faster, CT enterography is the first-line technique for the evaluation of small-bowel[4].

Contrast agents are generally divided into neutral enteric agents and positive enteric contrast agents. Neutral agents demonstrate CT attenuation number equal to that of water and positive enteric contrast agents contain barium or iodine, which have CT numbers much higher than those of adjacent enhancing structures[24]. Neutral agents are preferred for most small bowel indications because they allow greater visualisation of myriad of small bowel pathologies, which show differential enhancement as compared to the adjacent small bowel wall. When the pathology is suspected to be an intraluminal filling defect (e.g., polyposis syndromes) or serosal metastases, positive contrast agents are indicated[4].

Although a variety of neutral enteric contrast agents are available, many centres use mannitol which retards absorption of water across the small bowel wall, provides good small bowel distention compared with water alone. If patients present with difficulty in oral intake of these neutral contrast agents, they can complete ingestion of the required volume with adequate dilution with water. Patients need to be informed that enteric agents using mannitol, sorbitol or polyethylene glycol may cause loose bowel movements as the agent is expelled shortly after the test. However, in literature, no severe cases of dehydration have been documented[24].

CONTRAST AGENTS

Three types of contrast agents are used in imaging studies in radiology[45]:

1. Intravascular – iodinated water soluble agents
2. Gastrointestinal
3. Cholangiographic agents

Intravascular: Ionic, high osmolality, roughly five times the osmolality of blood; non-ionic, low osmolality, roughly twice or slightly more than the osmolality of blood; and isotonic agents—non-ionic dimers[24].

The reason why iodine is used is that at the X-ray energies used in CT, the mass attenuation coefficient for iodine is greater than that of adjacent soft tissues and blood. Soon after the intravenous injection of iodinated contrast agent, the initial CT images reveal major arterial enhancement predominantly the aorta, followed by a capillary or parenchymal enhancement also called blush and finally the venous opacification. The time of scan, amount and rate of contrast injection help in determining the anatomical structures which should be enhancing at a given phase of the CT scan[24].

Pharmacokinetics:

After a bolus intravenous injection, the initial plasma iodine concentration is dependent on the volume of the contrast injected and iodine concentration of the specific contrast agent. Ionic and non-ionic contrast agents are distributed throughout the intravascular, extravascular spaces and equilibrium is achieved usually 10 minutes after intravascular injection. They are excreted predominantly by the renal route by glomerular filtration. An ideal blood pool agent is an agent which has slow extravascular diffusion. One mg iodine per gram of tissue is roughly equivalent to an increase of 30 Hounsfield units (HU), which is about the limit for detection[24].

Generally, it is advisable to have optimal iodine concentration in the vasculature of interest to increase them above baseline by almost upto 100 HU[45]. With this intensity of enhancement, various pathological processes like major vessel thrombi, vascular fistulas and other similar conditions can be evaluated. Whether arterial phase is better than portal venous phase or even delayed scanning depends on the organ of interest and the clinical data sought. For imaging of the liver, arterial and portal venous phase timings are roughly 20 to 30 seconds. These short time intervals between phases are easily achieved with MDCT. A typical contrast enhanced CT examination consists of a pre-contrast or plain scan, followed by scanning after the initial bolus of contrast reaching the structure of in question[24].

GASTROINTESTINAL CONTRAST AGENTS:

Barium sulphate

Barium sulphate is a crystalline powder having a molecular weight of 233[24]. Barium has high specific gravity of 4.5 and therefore patients tend to experience that a small cup of barium suspension "feels heavy." The terms thick and thin solutions should only be used with reference to viscosity of barium. Ingestion of a barium sulfate suspension tends to be constipating as opposed to neutral contrast agent which often increase the bowel movements[24].

Positive Contrast Agents

Positive contrast opacification (>75 HU) of the bowel is achieved by giving 1 - 2% barium suspensions or 2% to 3% solutions of iodinated water-soluble agents (Figure 18). This low percentage barium requires some preparations aimed for CT in specific, in which additives are used to make sure that the barium remains in suspension form. In most patients with normal bowel habits the oral contrast material reaches the ileo-caecal region after 45 minutes of drinking the same. Some clinical conditions with prolonged transit times include hypothyroidism, recent history of surgery, electrolyte disturbances, collagen vascular diseases like scleroderma and intestinal obstruction. In contrast, patients who have hyperthyroidism, carcinoid, islet cell tumour, or have some infections like cryptosporidiosis show faster intestinal transit time. Water-soluble agents are preferred in patients with trauma or in suspected hollow viscus perforation, so that they can be taken up for immediate surgery[24].

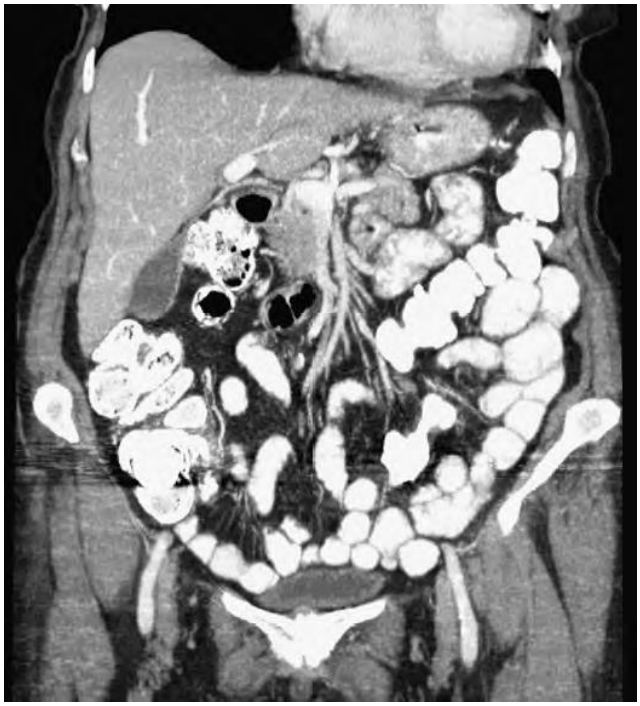

Figure 18 Coronal reformatted image shows good distention of the small bowel and colon by positive contrast. The high-density intraluminal material limits assessment of the enhancement of the bowel wall.

Neutral contrast agents

Neutral contrast agents exhibit attenuation value of 0-25 HU have many advantages over positive oral contrast agents for evaluating serosal, mucosal and mural disease. They allow excellent exhibition of mural enhancement of the bowel (Figure 19). Neutral contrast agents also enhance the performance of other three-dimensional techniques and CT angiography. Neutral contrast agents include lactulose, milk, water, 0.1% solution of barium

(VoLumen), and water with Mannitol or polyethylene glycol. For the upper gastrointestinal tract, water can be used as a neutral contrast agent. It causes optimal distension of the stomach and duodenum[24].

Water can be used as an effective neutral contrast agent for the upper gastrointestinal tract, especially the stomach and duodenum. But it is often not helpful in distention of the distal small bowel because it is usually almost completely absorbed before reaching the distal ileum. In the preoperative staging and evaluation of various hepatobiliary malignancies, neutral contrast agent is recommended in conjunction with CT angiography[24].

Negative contrast

CT gastrography is a technique used for the staging and diagnosis of upper gastrointestinal malignancies. In CT colonography, per rectal CO_2 or air insufflation is done[24].

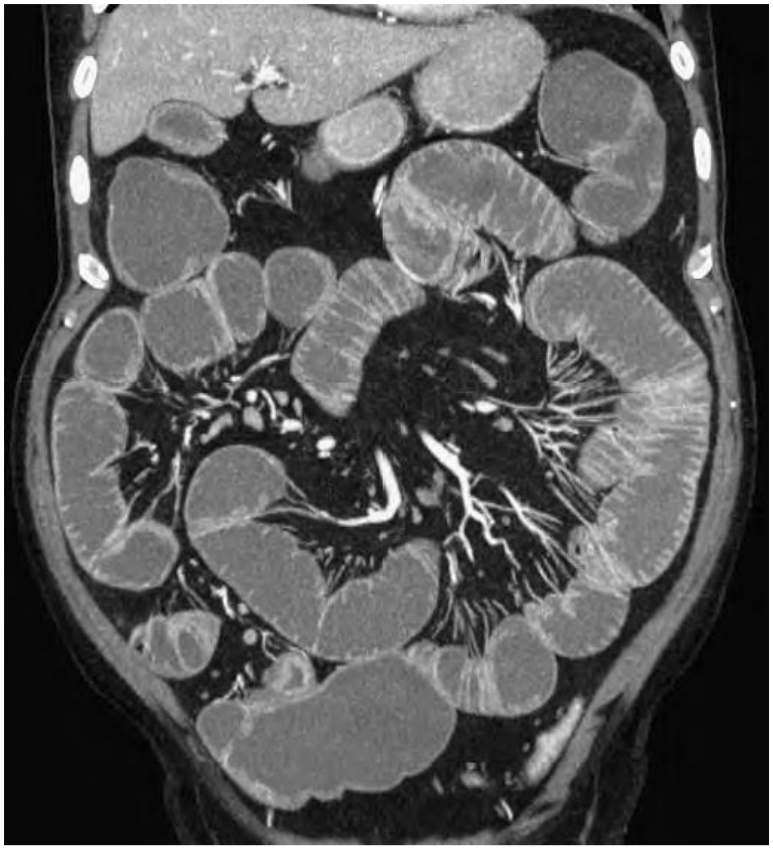

Figure 19 Neutral contrast agent

Normal bowel wall assessment

The most common imaging presentation of any bowel pathology is bowel wall thickening, changes in the density and enhancement pattern of the bowel wall caused by fat, gas, edema, haemorrhage or tumour. Two most common pitfalls in the interpretation of CECT abdominal studies are the pseudo-thickening of the inadequately distended bowel loops, which can mimic pathological thickening and misinterpretation of an inadequately enhanced bowel loops of an abdominal mass[31].

The normal small bowel wall thickness measures between 1 and 2 mm in a well distended state with a positive, neutral, or negative contrast medium. In collapsed state, the mural thickness of the small bowel may falsely show increased values measuring between 2 and 3 mm. The normal small bowel wall shows best enhancement during the enteric phase which corresponds to 40 seconds after the contrast injection and is almost the same as the portal venous phase. Some researchers also think that 40 seconds is the optimum time to scan in patients with Crohn's disease[46].

A major limitation of the wall of collapsed small bowel loop segments are that they have more attenuation than the wall of fully distended loops, sometimes may mimic pathology. Anatomically, the number of folds in decreasing order of frequency are – duodenum > jejunum > ileum, hence the duodenum enhances more than jejunum and ileum[24]. For diagnosis of subtle findings in bowel pathologies, thin reconstructions can be used on MDCT in multiple planes[24].

Orthogonal views i.e. axial, coronal and sagittal are very helpful in optimal evaluation of the bowel. The axial and coronal planes especially are most helpful. For example, in the diagnosis of ischemic bowel - mesenteric artery occlusion is an important part of the investigation. The coronal plane more strikingly resembles the schematic anatomy which is followed in medical schools, hence the gastroenterologists and surgeons are more familiar and comfortable with coronal plane[47].

While viewing CT images of the small bowel, the scrolling on a workstation from cranial to caudal, back and forth and also anterior to posterior, allows us to clearly evaluate and follow the contiguous bowel loops, specially the ileum and jejunum which have a long and convoluted course. Also, viewing the images in all three planes i.e. axial, coronal and sagittal helps us to distinguish the small bowel pathology from mesenteric abnormalities. For diagnosis of hypervascular lesions, the bowel assessment can be done in narrow windows. Gradually, after the assessment of bowel changing the level and window back to a soft tissue will help in identification of mesenteric pathologies, which might have been obscured in the images with narrow windowing and levelling[47]

Mannitol as oral contrast agent

The discovery of mannitol is attributed to Joseph Louis Proust in 1806.Mannitol is a white, crystalline, water-soluble, slightly sweet naturally occurring alcohol, used as a dietary supplement and dietetic sweetener. The molecular formula of mannitol is $C_6H_{14}O_6$ and is an osmotic diuretic[24] (Figure 20).

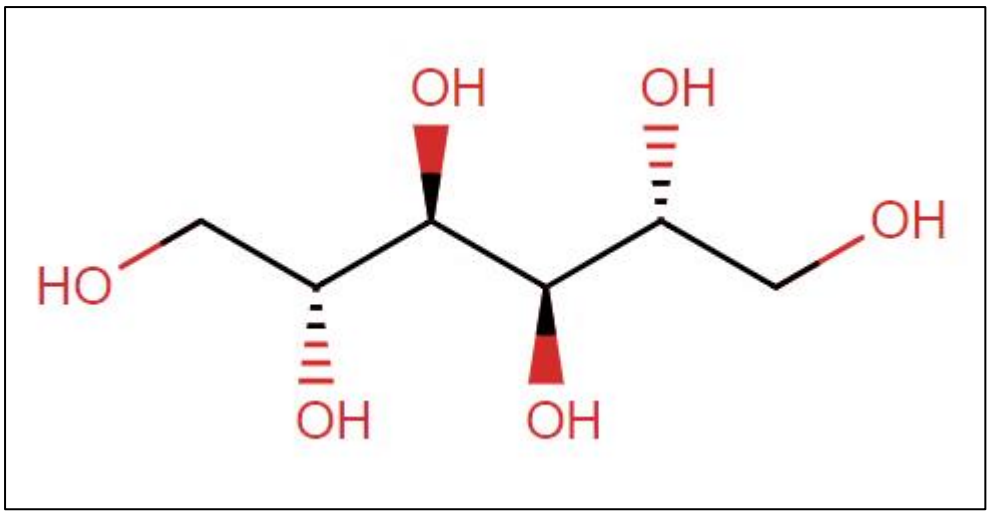

Figure 20 Molecular formula of mannitol[48]

Mechanism of action:

Mannitol is almost completely filtered by the glomerulus and there is poor tubular reabsorption, which increases the osmolarity of the glomerular filtrate. An increase in osmolarity of the glomerular filtrate limits tubular reabsorption of water and inhibits the renal tubular reabsorption of sodium, chloride, and other solutes, thereby causing diuresis. In addition, mannitol raises the blood plasma osmolarity, resulting in increased inflow of water from tissues into interstitium and plasma[48].

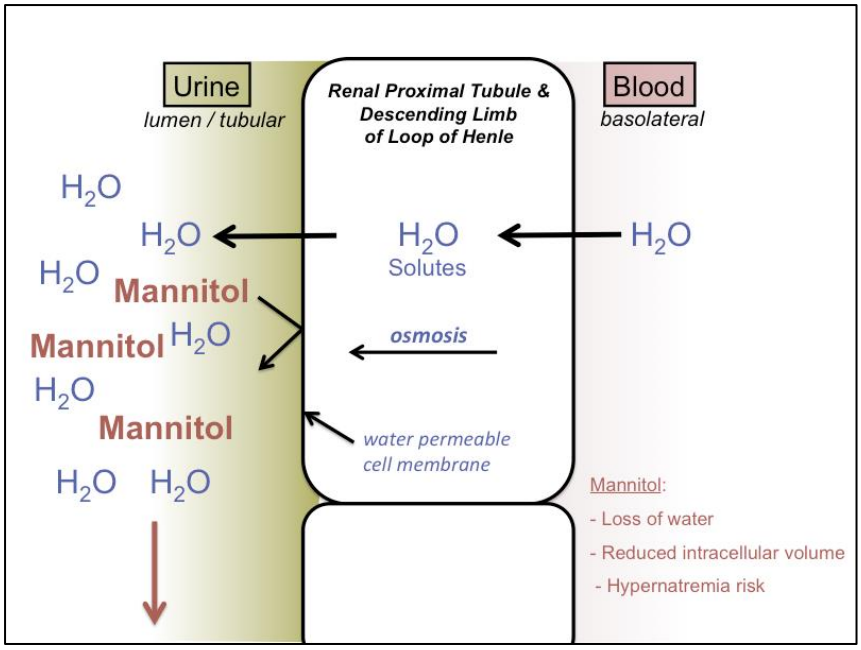

Figure 21 Mechanism of action of mannitol.

Mannitol is a sugar alcohol that does not cross cell membranes, and acts as an osmotic diuretic that inhibits sodium and water reabsorption in the proximal tubule, as well as the loop of Henle (Figure 21). It produces a greater loss of water compared to sodium and potassium[48].

It is helpful in evaluation of bowel owing to its osmotic diuretic property, mannitol helps in homogenous distension of the bowel loops especially the small bowel. It is given in diluted form in large volumes over a time duration of about 45 minutes to cause adequate distention of the small bowel[2].

CLINICAL STUDIES

A study by Ros PR et al., emphasised the advantage of current-generation MDCT scanners and proved that there is increased anatomical coverage with thinner sections, which provide high-quality multiplanar reconstruction (MPR) images and fewer motion artifacts[49].

Bowel distension is an important prerequisite in CT evaluation as the collapsed loops might obscure the underlying bowel characteristics. Luminal distension and mural fold visualization are the important factors in gastrointestinal tract imaging[2].

Study done by Elamparidhi et al., on 75 patients who were randomly divided into 3 groups and administration of water, Mannitol and positive oral contrast was done before the CECT study. In this study, there was significant difference in distension at all segments of small bowel except the duodenum. This study has shown that oral mannitol is palatable, economical, easily accessible, has better luminal distension than positive oral contrast, allows better luminal and mural differentiation. Mannitol can be considered as an ideal neutral oral contrast as it can provide excellent bowel distension and provide better appreciation of bowel wall enhancement and mural pattern when compared with water and iodine-based oral contrast[1].

A study done by Prakashini K et al., on 300 patients each divided into three groups concluded that small bowel distension until the jejunum was comparable among all three

contrast groups. However, the distal ileal loops, ileocaecal junction and large intestinal distension was excellent with mannitol. In addition to the good distension, the visualization of mural/mucosal features and homogeneity of bowel loops was significantly better with mannitol as oral contrast agent[2].

A study by Zhang LH et al., was conducted on Thirteen volunteers and 38 patients with various small bowel pathologies. A total of 1500 ml of mannitol was administered and helical CT scanning was performed. The findings were evaluated by two radiologists and they followed a four point scale for qualitative evaluation. This study concluded that MDCT enterography with mannitol as oral contrast agent proved be is a simple, rapid, non-invasive and effective method of causing small bowel distension and hence evaluating small bowel disease. It also concluded that mannitol has good patient tolerability with no major side effects seen after its administration[4].

Another study conducted by Wong J et al., on 50 patients each divided into two groups where 25 individuals were given Mannitol and the rest were given VoLumen as oral contrast agent before the CT scan. This study concluded that mannitol produces CT imaging studies of a far superior quality than VoLumen, with comparable patient tolerability of both agents. Also, mannitol comes with the advantage of wider availability and better affordable neutral contrast agent[50].

A study conducted by Wang YR et al., on 80 patients who were randomly divided into four groups and given diluted lactulose, Mannitol, milk and plain water respectively concluded that mannitol and diluted lactulose solution cause the entire small bowel demonstrate consistent

dilatation, post intravenous iodine contrast injection, the enhanced CT scanning could clearly show the intestine wall and also the extra-intestinal mesenteric structures. The above two oral contrast agents were proven suitable for better bowel evaluation by CECT. Milk solution was not well tolerated by the patients since they had to consume 1.5 litres[51].

MATERIALS AND METHODS

SOURCE OF DATA

This was a hospital based observational study performed over a period of twelve months from December 2018 to November 2019 on 90 patients referred for CECT abdomen with extra-intestinal pathologies at Department of Radiodiagnosis, R. L. Jalappa Hospital and Research Centre attached to Sri Devaraj Urs Medical College, Kolar. Informed consent was taken from individuals for their willingness to participate in the study.

METHODS OF COLLECTION OF DATA

Baseline data were collected from the patients along with pertinent clinical history and relevant lab investigations. Individuals were randomly divided into three groups and were given either 1500 mL of plain water (Group 1), 1500 mL of 3% mannitol (Group 2), or iodinated oral contrast (15 mL in 1500 mL) (Group 3), 45 minutes to one hour prior to the CT scan. They underwent unenhanced CT study followed by contrast enhanced CT study with standard protocol using 16-slice Siemens® Somatom Emotion® scanner.

Sample size calculation

Keeping the minimum mean difference of bowel distension between the groups as 0.5 at the level of jejunum with standard deviation of 0.7 and 0.4, at 95% confidence interval, 80% power, the minimum required sample size was calculated to be 20 in each of the three groups i.e. total of 60 participants[1].

Assumptions:

Minimum mean difference between the groups = 0.5

Standard deviations: 0.7 and 0.4

Confidence Level: 95%

Power: 80%

Formula Used,

$$N = 2 * S_p^2 * \frac{\left[Z_{1-\frac{\alpha}{2}} + Z_{1-\beta}\right]^2}{\mu_d^2} \quad \text{where} \quad S_p^2 = \frac{S_1^2 + S_2^2}{2}$$

S_1: Standard deviation of the first group

S_2 : Standard deviation of the second group

μ_d : Mean difference between Samples

α : Significance level

1-β: Power

Based on the assumptions,

$S_1 = 0.7$

$S_2 = 0.4$

$S_p^2 = (S_1^2 + S_2^2)/2 = (0.7^2 + 0.4^2)/2$

$= (0.49+0.16)/2 = 0.325$

μ_d= 0.5

$Z_{1-\alpha/2}$= 1.96 (from Normal tables) α= 95%

$Z_{1-\beta}$ = 0.84 β=20% or power=1-β= 80%

Substituting the above values in the formula:

$N= 2*0.325*[1.96+.84]^2/0.5^2$

$= 2*(0.325) *(7.84)/0.25$

$= 20.384$ (~ 20 for each group)

Since we have 3 groups in our study, the overall sample size was kept at 60.

Inclusion criteria:

- Patients undergoing CECT abdomen for extra-intestinal pathologies.
- Individuals above 18 years of age.

Exclusion criteria:

- Patients who are allergic to intravenous contrast.
- Patients with deranged renal function tests.
- Pregnancy.

CT protocol

Plain CT was performed with the patient in supine position using the breath holding technique. Contrast enhanced CT was performed with multiphase study, which included arterial, venous and delayed sequences. The details were as follows:

Slice thickness – 5 mm plain and contrast.

Pitch – 1.2

kVp – 130 kVp for plain study followed by 110 kVp for arterial phase and 130 kVp for venous and delayed phases.

mAs – CARE Dose 4D®, which is automated exposure control (AEC) provided by Siemens.

Scan area – From base of lungs to pelvis

Type of CT scan – Spiral/ helical CT was done.

Contrast agent – Iohexol 300 (Ultravist®) was injected intravenously at the rate of 3.5 to 4 mL/s using pressure injector (Medtronic®). Quantity of contrast used was based on body weight and ranged from 1.25 to 1.5 mL/kg body weight.

Bolus tracking was used to initiate the CT scan following injection of iv contrast.

Arterial phase: The arterial phase was calculated at 3-5 seconds following bolus trigger or about 15-20 seconds following contrast administration. Slice thickness of 5 mm was used, which was then reformed to 0.75 mm thin sections. The thin sections were used to create 3D images.

Venous phase: The venous phase was calculated about 25-30 seconds following completion of arterial phase or about 65-70 seconds following contrast administration. Slice thickness of 5 mm was used, which was reconstructed to 1.5 mm for 3D reformations.

Delayed phase: The delayed phase was calculated about 240 seconds following completion of venous phase or 300 seconds following contrast administration. Slice thickness of 5 mm was used, which was reconstructed to 1.5 mm for 3D reformations.

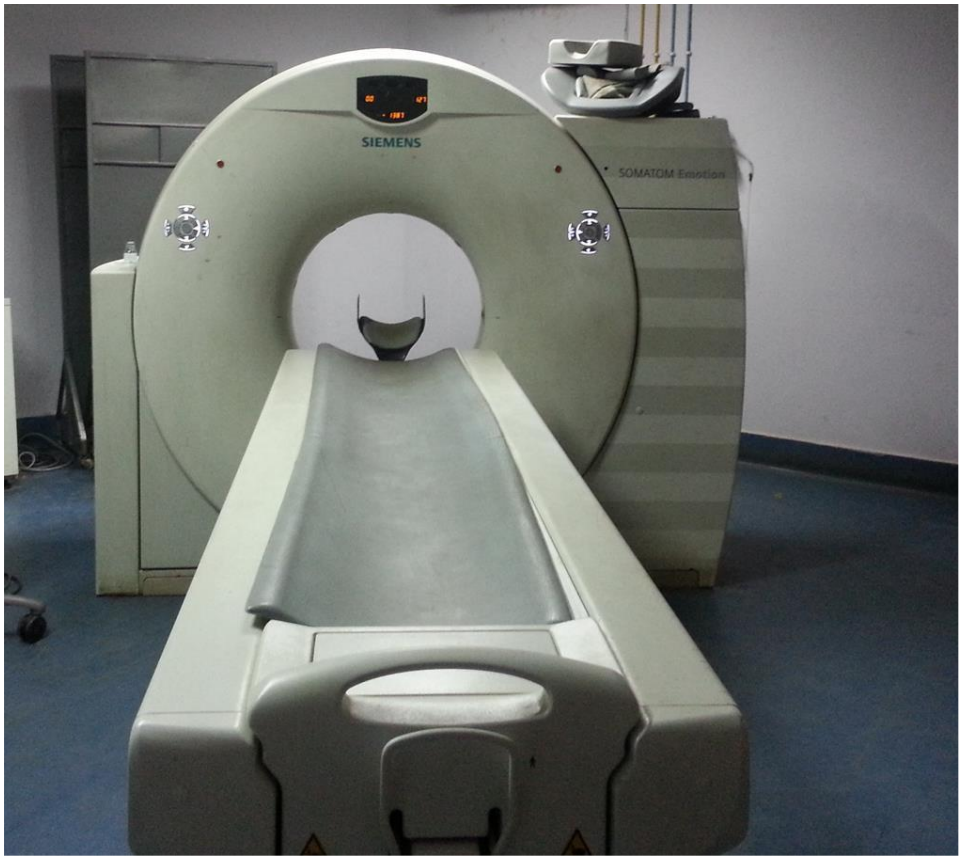

Figure 22 SIEMENS® SOMATOM EMOTION 16® CT scanner used in the study.

Image Assessment

The images were transferred to work station (Myrian ® or Osirix ®), where the studies were reported by two radiologists. Analysis of the images was done by two radiologists who were blinded to the neutral luminal contrast agents, i.e., mannitol and water.

The radiologists were aware of the clinical question for the study and had access to patient's files, results of other imaging tests (such as ultrasound and X-rays) and results of any previous studies in the same patient. The radiologists had 10 years and 5 years of experience in cross sectional imaging. Quantitative and qualitative evaluation of bowel distension was done using CECT abdomen images. Axial, coronal and sagittal reformatted images of the venous phase were chosen for evaluation. Bowel distension was evaluated at various levels: duodenum (one level), jejunum, ileum at two levels and lastly the ileo-caecal junction. The measurement of bowel distension was taken on axial and coronal planes taking the outer to outer diameter into account. The duodenum was measured at the second part of the duodenum or the portion showing the maximum distension. The jejunum was measured at two points at the level of superior mesenteric artery and ileum was measured at the bifurcation of the iliac vessels and in the right iliac fossa. The values and findings of both radiologists were compared and mean values were acquired at each anatomical level.

Quantitative and qualitative analysis of the bowel for distension, mural fold pattern, enhancement and image quality was analyzed by diameter measurement and point scale system at at various anatomical levels, which included duodenum, jejunum, ileum and ileocecal junction. Qualitative examination of bowel loops was done in the three groups by using a continuous 4-point scale (0-3, fair to excellent, percentage of small bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility).

1. Score 0-Fair (<25%)
2. Score 1-Good (25-50%)
3. Score 2 Very good (50-75 %)
4. Score 3- Excellent (>75%)

The score was given based on the percentage of bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility. A score of 0 indicated <25% of bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility and score of 3 indicated >75% of bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility[2].

Additionally, the visibility of mural fold characteristics across all the groups was measured using semiqualitative score. In this system, score 0 was given if the bowel loops were partially or completely collapsed with was poor mural fold visibility; score 1 was given if mural fold visibility was good and score 2 when there was excellent mural fold visibility.

Qualitative assessment of bowel distension was performed at various levels, which involved caecum, ascending colon, splenic flexure and transverse colon. Features like haustral visibility and degree of large bowel distension were graded as good, average and poor based on subjective assessment.

Statistical analysis

Data was entered into Microsoft excel data sheet and was analyzed using SPSS 22 version and OpenEpi software. Categorical data was represented in the form of frequencies and proportions. Chi-square test was used as test of significance for qualitative

data and analysis of variance (ANOVA) test was used as test of significance for quantitative data. *P* value <0.05 was considered as statistically significant.

RESULTS

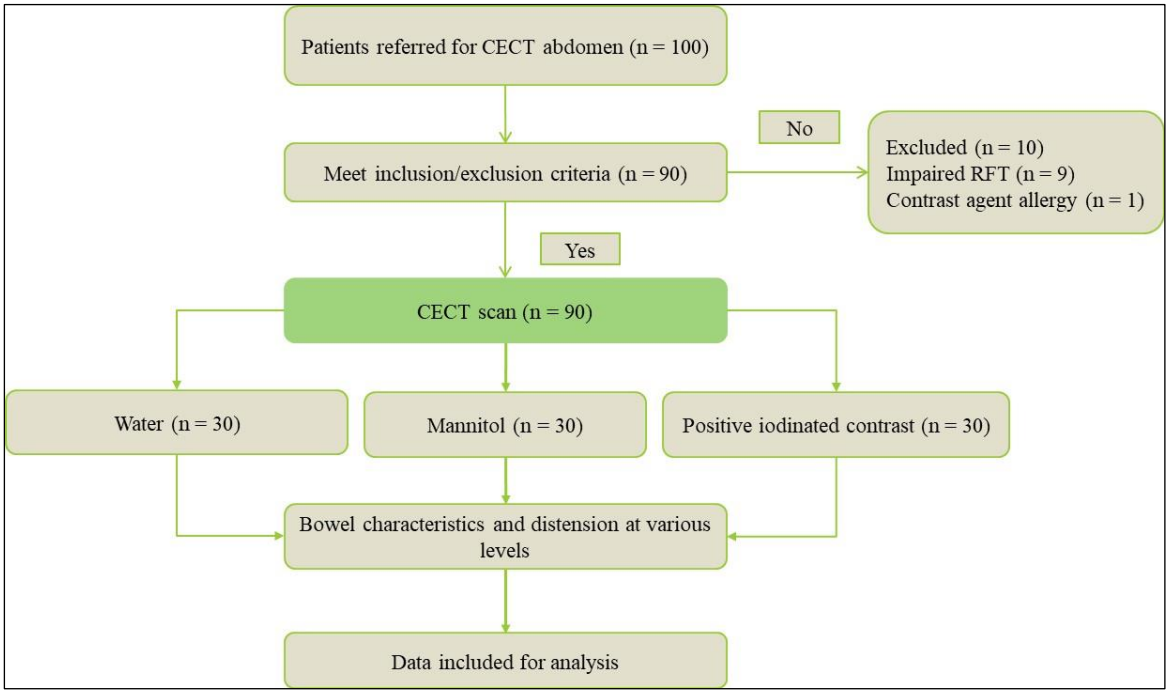

Figure 23. Study design schematic. CECT – contrast enhanced computed tomography RFT – renal function test

In our study, 100 patients who fit the inclusion criteria were evaluated of whom 10 patients were not included due to abnormal renal function tests (n = 9) or history of contrast allergy (n = 1). Finally, the study included 90 patients, who were randomly divided into either of the three groups (n = 30 each) (Figure 23).

Age and Gender Distribution

Table 4. Age and Gender Distribution of Cases

	Water	Mannitol	Positive contrast	P
Age (in years) (mean ± SD)	51 ± 11.86	44.43 ± 14.92	45.5 ± 16.87	0.18; NS
Gender				
Males	15	12	18	NS
Females	15	18	12	
Total	30	30	30	
NS = not significant; SD – standard deviation				

We included 90 patients in our study who were randomly distributed into three groups (n = 30 in each group). The mean age of patients in Group 1 (Water) was 51 ± 11.86 years (mean ± SD), Group 2 (mannitol) was 44.43 ± 14.92 years (mean ± SD) and Group 3 (positive iodinated contrast) was 45.5 ± 16.87 (mean ± SD). There was no significant difference between the age group of patients in either of the groups (*P* = .18; not significant) (Table 4). Total mean age was 46.9 ± 14 years with range of 18-75 years. Out of 90 cases, there were total 45 males and 45 females (Figure 24) with no significant difference between gender distribution across the three groups.

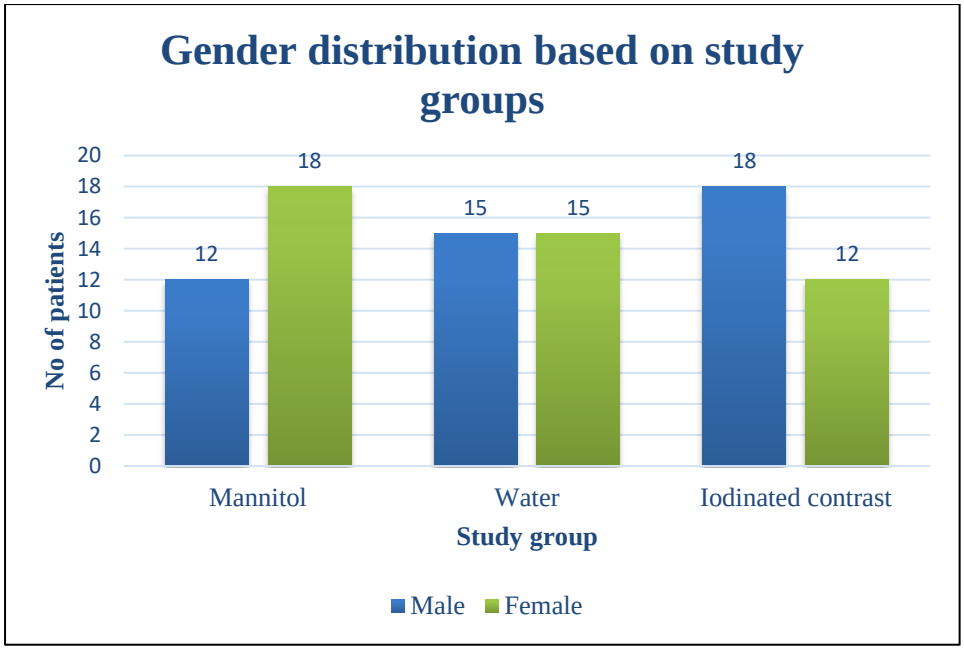

Figure 24. Gender-wise distribution of patients across the study groups.

Quantitative evaluation

Table 5. Mean Bowel Diameter at Different Locations Across all the Groups.

Mean bowel diameter (in cm)					*P* (Mannitol vs water)	*P* (Mannitol vs PIC)	*P* (Water vs PIC
Type of contrast		**Water**	**Mannitol**	**Positive iodinated contrast**			
Bowel segment	D	1.89 ± 0.33	2.28 ± 0.36	2.01 ± 0.33	<.001	<.001	.15
	J1	1.84 ± 0.31	2.23 ± 0.36	1.74 ± 0.29	<.001	<.001	.23
	J2	1.69 ± 0.3	2.19 ± 0.39	1.73 ± 0.37	<.001	<.001	.62
	I1	1.47 ± 0.34	1.93 ± 0.31	1.48 ± 0.26	<.001	<.001	.89
	I2	1.45 ± 0.3	1.87 ± 0.32	1.51 ± 0.28	<.001	<.001	.4
	ICJ	1.01 ± 0.22	1.17 ± 0.24	0.96 ± 0.22	.006	<.001	.41

D – Duodenum; J1, J2 – jejunal sites; I1, I2 – ileal sites; ICJ – ileocecal junction, PIC – positive iodinated contrast

The mean distension at duodenum was 1.89 ± 0.33 cm (mean ± SD) with water, 2.28 ± 0.36 cm (mean ± SD) with mannitol, and 2.01 ± 0.33 cm (mean ± SD) with positive oral contrast. Overall, maximum luminal distension was seen at the level of duodenum followed by J1 site (at the level of origin of SMA) across all the groups (irrespective of type of contrast). The least luminal distension was seen at the level of ileocecal junction across all subgroups. Among all the groups, maximal luminal distension was seen in the mannitol group, irrespective of the site (Table 5; Figure 25). Overall, there was significantly better luminal distension with mannitol when compared with water (*P*<.001 at all sites except ICJ;

P = .006 at ICJ) or positive iodinated contrast (*P*<.001 across all sites). The luminal distension provided by water and positive iodinated contrast was similar with no statistically significant difference among these groups at all sites (Table 5).

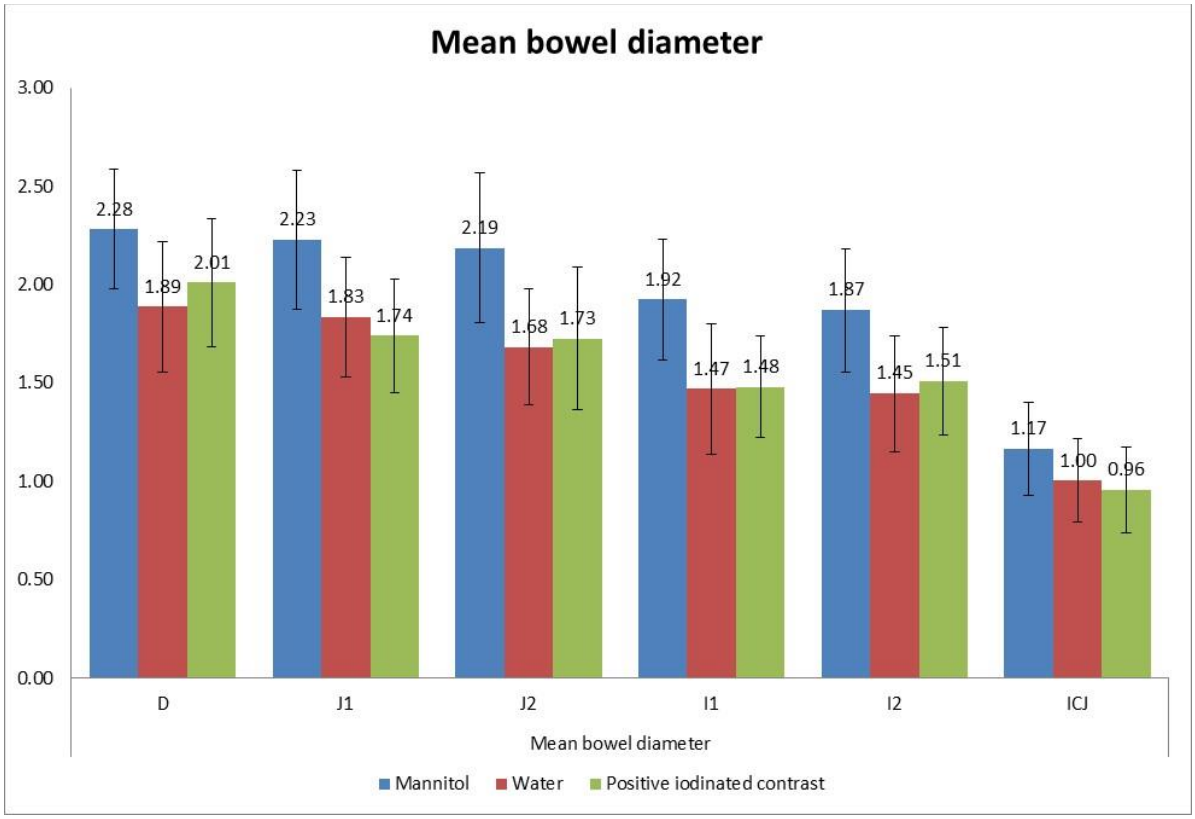

Figure 25. Mean bowel diameter across various groups.

Qualitative evaluation

Table 6. Qualitative Evaluation of Small Bowel Loops Across All Groups

	Water		Mannitol		Positive iodinated contrast	
Grade	Count	%	Count	%	Count	%
0	8	27%	1	3%	2	7%
1	14	47%	3	10%	8	27%
2	5	17%	8	27%	13	43%
3	3	10%	18	60%	7	23%
Total	30		30		30	

P = significant across all groups (<.001). *P* is significant between mannitol and water (*P*<.001), between mannitol and positive oral contrast (*P* = .03), and between water and positive oral contrast (*P* = .01).

Qualitative evaluation was performed to assess the bowel loops for adequate distension or homogeneity of luminal contents or fold visibility. It can be seen from Table 6 that 60% of patients using mannitol showed excellent bowel distension or homogeneity of luminal contents or fold visibility and only 10% of patients who had water as oral contrast showed excellent distension. Furthermore, nearly half of patients (47%) who had water as oral contrast showed only good score (grade 1) and nearly half of patients who used positive iodinated contrast (43%) reported a very good score. The degree of bowel distension or homogeneity of luminal contents / fold visibility was significantly better with mannitol, when compared with water or positive iodinated contrast (*P*<.001) and degree of bowel distension or homogeneity of luminal contents was significantly better with positive iodinated contrast when compared with water (*P* = .01). Water was the least effective agent in achieving adequate bowel distension or homogeneity of luminal contents. Overall, mannitol showed better bowel distension or homogeneity of luminal contents / fold visibility followed by positive iodinated contrast and water.

Mural fold characterisation

Table 7. Comparison of mural characteristics

	Water		Mannitol		Positive iodinated contrast	
Score	**Patients**	**%**	**Patients**	**%**	**Patients**	**%**
Score 0	19	63.3 %	2	6.66 %	27	90.0 %
Score 1	8	26.6 %	11	36.67 %	3	10.0 %
Score 2	3	10.0 %	17	56.67 %	0	0
Total	30		30		30	

*P<.001 for mannitol versus positive oral contrast and water. P<.001 for water and mannitol and for mannitol and positive oral contrast; P<.05 for water and positive oral contrast

Table 7 shows the mural fold visibility across the three groups. Mannitol showed excellent mural fold visibility in more than 50% of cases (n = 17; 56.67%) and good mural fold visibility in another 11 patients (36.67%) and only two cases showed poor mural fold visibility. The degree of mural fold visibility was significantly better with mannitol when compared with water or positive iodinated contrast (P<.001). In contrast, water showed good or excellent mural fold visibility (scores 1 and 2) in 11 patients (36.67%) and poor mural fold visibility in 63.33% of cases (n = 19). Positive iodinated contrast showed poor mural fold visibility in 90% of the cases (n = 27). Water showed better mural fold visibility when compared with positive iodinated contrast (P<.05). Overall, mannitol showed better mural fold visibility followed by water and positive iodinated contrast.

Overall mannitol showed better bowel distension or homogeneity of luminal contents / fold visibility and mural fold visibility, when compared with water and positive iodinated contrast. Water showed better mural fold visibility when compared with positive iodinated contrast, while positive iodinated contrast showed better bowel distension or homogeneity of luminal contents.

Large bowel evaluation

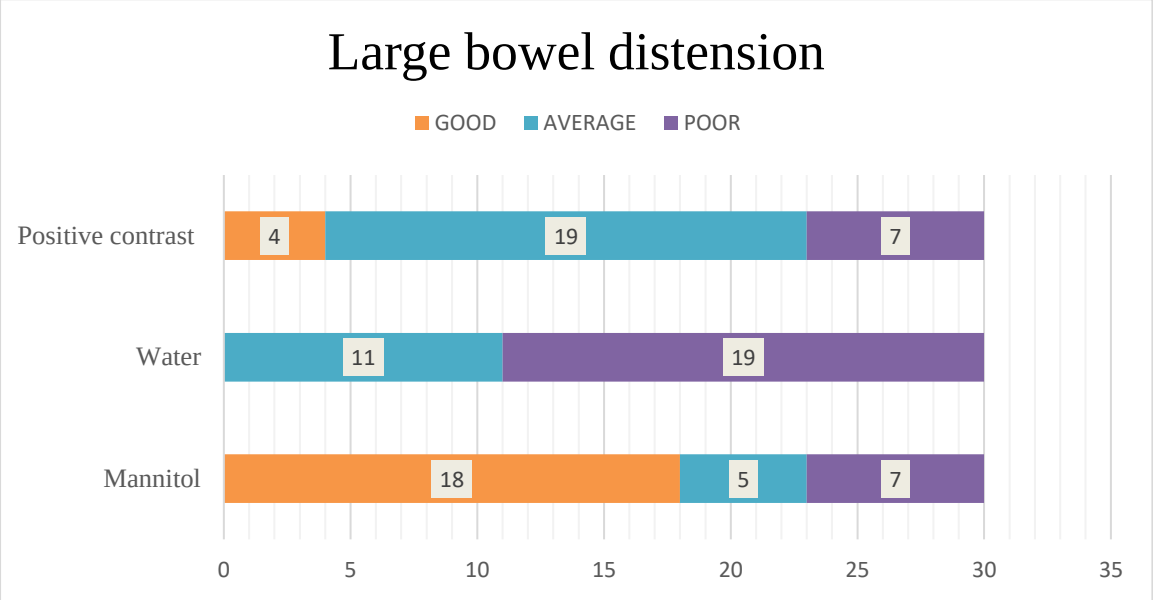

Figure 26. Large bowel distension with water, mannitol and positive iodinated contrast.

Mannitol showed good large bowel distension in 18 cases (n = 60%) with average distension in five patients (16.67%) and poor distension in seven patients (23.33%). None of the patients who had water showed good large bowel distension with majority of patients showing poor large bowel distension (n = 19; 63.3%) and remaining 11 patients showing average large bowel distension (36.7%). Patients who received positive iodinated contrast showed average large bowel distension in 19 cases (63.33%), poor large bowel distension in seven cases (23.33%) and good large bowel distension in four cases (13.34%) (Figure 26). Degree of large bowel distension was significantly better with mannitol when compared with water or positive iodinated contrast ($P<.001$). Similarly, positive iodinated contrast showed significantly better large bowel distension when compared with water ($P<.05$).

IMAGES

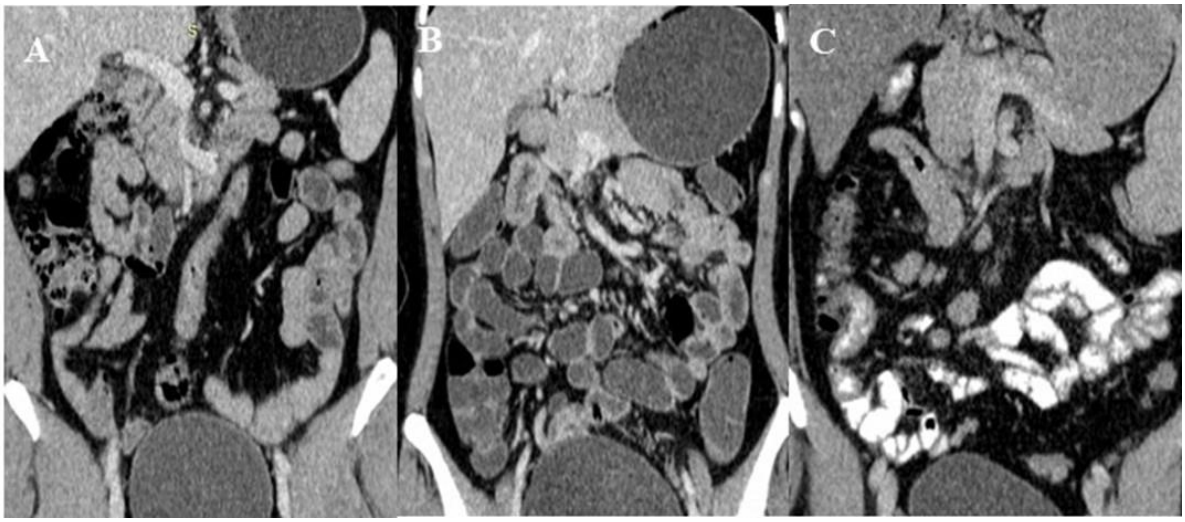

Figure 27 Coronal reformatted CECT image showing bowel distension with oral plain water (A), bowel distension with mannitol (B) and bowel distension with positive oral contrast (C). Note the excellent bowel distension with mannitol when compared with water and positive iodinated contrast.

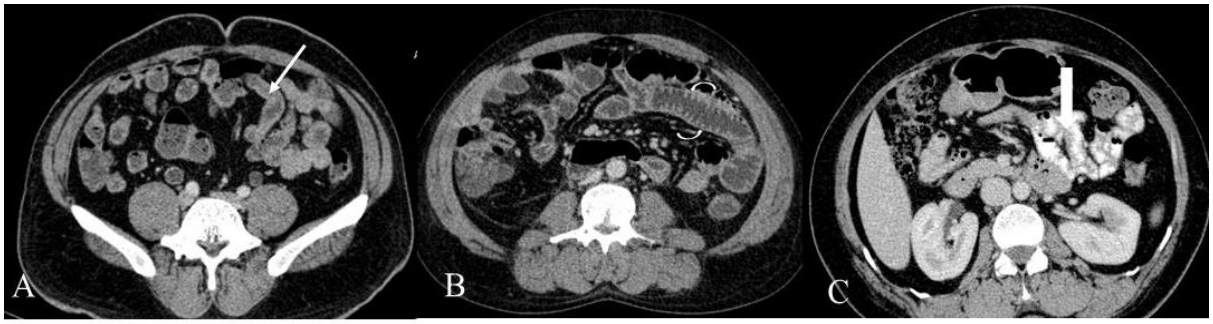

Figure 28 Axial CECT Abdomen in patient who was given water showing poor mural features (thin white arrow), in patient who was given mannitol showing good mural fold visualization (curved white arrows) (B) and patient who was given positive iodinated contrast (C), which shows suboptimal mural fold visualization (thick white arrow).

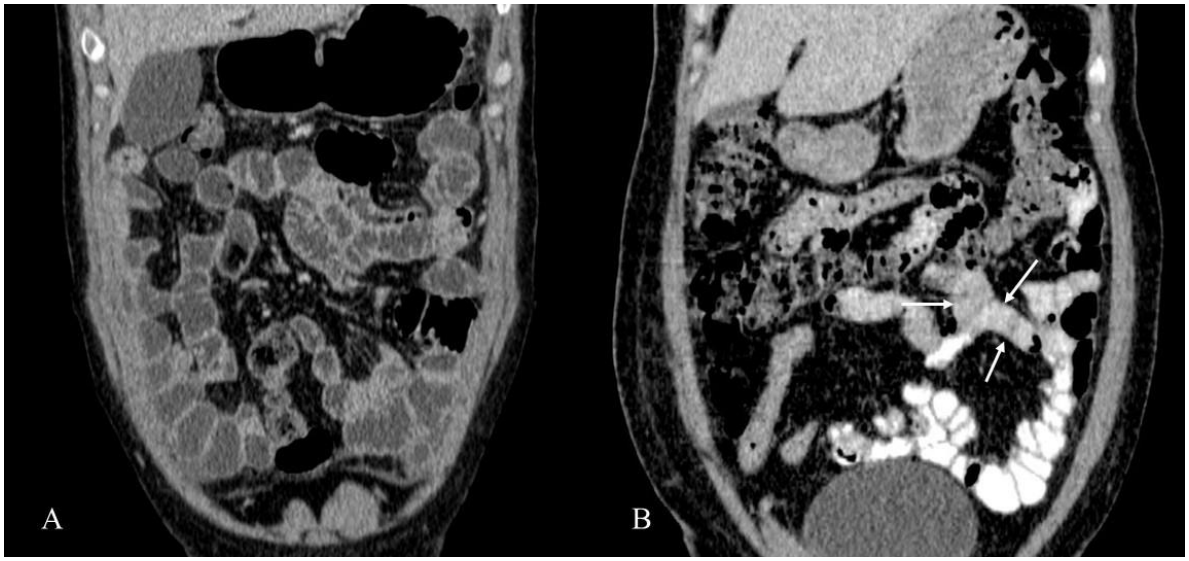

Figure 29 Coronal CECT Abdomen in patients given mannitol (A) and positive oral contrast (B). Note the good mural fold visualization in patient who was given neutral oral contrast like mannitol and suboptimal visualization of mural folds in patient with positive oral contrast (white arrows).

DISCUSSION

The high resolution provided by MDCT images has changed the approach to small bowel diseases. The excellent spatial and contrast resolution provided by MDCT helps in better visualization of bowel loops[1]. The ability of MDCT to both visualize bowel wall and assess bowel lumen provided additional data, which was not provided by barium studies. It has been argued that an ideal endoluminal contrast agent should provide optimal luminal distension, provide adequate mural details and be of low attenuation, which has resulted in the search for an ideal neutral contrast agent[2].

Three types of oral contrast agents exist i.e. positive, negative and neutral oral contrast agents. Neutral contrast agents are always preferred over positive or negative oral contrast agents as they cause homogenous distension of the bowel loops. The use of negative contrast agents is limited as they cause severe type of cramping abdominal pain. Ideal oral contrast must have low attenuation values; provide adequate bowel distention, demonstrate mural fold visualization and have less artifact formation[1,2].

The addition of oral contrast agents to the routine abdominal CT examinations has increased the sensitivity of detecting subtle small bowel lesions which could not be detected in conventional CECT studies[1,2].

In our study of 90 patients, we evaluated the distension and enhancement pattern of bowel with water, mannitol and iodinated contrast. The mean age of patients in Group 1 (Water) was 51 ± 11.86 years (mean ± SD), Group 2 (mannitol) was 44.43 ± 14.92 years (mean ± SD) and Group 3 (positive iodinated contrast) was 45.5 ± 16.87 (mean ± SD). There was no significant difference between the age group of patients in either of the groups (*P* = .18; not significant). Total mean age was 46.9 ± 14 years with range of 18-75 years. Out of 90 cases, there were total 45 males and 45 females.

Our results are similar to study by Prakashini et al., conducted in Karnataka, who reported a mean age of 48 years (range 20 to 70 years). The authors had greater male population in their study (62.67%)[2], which is in contrast to our study, where we had equal distribution of males and females. Elamparidhi et al., in their study in Puducherry (south India) also reported a similar age group distribution in their study involving 75 patients with mean age of 46 ± 11.4 years (mean ± SD) (water group), 42.9 ± 11.4 years (mean ± SD) (mannitol group) and 48.8 ± 10 years (mean ± SD) (positive contrast group). The authors also reported a slight male preponderance in their study (male:female ratio of 8:7)[1]. This probably reflects the mean population age of patients in this region. Berther et al., reported a nearly equal male:female ratio in their study (101:99), which is consistent with our study[52].

In our study, all the patients consumed 1500 mL of endoluminal contrast. In our experience, we have observed that for adequate bowel distension, use of at least 1500 mL of endoluminal contrast is necessary. Various studies have used different amount of endoluminal contrast ranging from 1000 mL to 1800 mL[1,2,52,53]. Most of the studies however have used 1500 mL of endoluminal contrast[1,2,54], which is consistent with our study.

We performed contrast after about 45 minutes to one hour after initiation of oral contrast medium. In our experience, adequate bowel distension is seen following 45 min to one hour of contrast. Our protocol is supported by study performed by Meindl et al., who compared the luminal distension with short protocol of oral endoluminal contrast (1000 mL for a period of 60 minutes) and prolonged protocol (2000 mL for a period of 120 minutes). The authors reported that small intestine showed adequate distension and contrast with both short and prolonged protocols. Additionally, the authors recommended prolonged protocol when evaluating specifically for ileocecal junction and large bowel[55]. Many other studies have also followed protocol of performing study one hour after starting oral contrast[1,2,52,54], which is consistent with our study.

High osmolarity of an endoluminal contrast can be considered to be single most important factor governing the bowel distension[2]. Mannitol is an osmotic agent, which is cheap and is easily available and hence was considered as a potential replacement to plain water in our study[53]. Water mixed with mannitol and the physiologic secretions of the upper GI tract have a similar neutral fluid attenuation, which provides for homogeneous images on CT[2,52]. Additionally, mannitol mixed with water has been shown to stay for longer duration in the intestinal lumen, which additionally augments its ability to provide consistent bowel dilatation[53]. Diluted positive iodinated contrast also has some osmotic effect; however, it is lesser when compared with mannitol[52]. Furthermore, diluted positive iodinated contrast does not induce osmotic gap and hence it gets absorbed along the GIT as it passes through small bowel loops[54]. Water has been shown to be rapidly absorbed by the bowel mucosa and

therefore is known to cause suboptimal bowel distension in the distal small bowel loops[2], which was consistent with our study.

In our study there was significantly better luminal distension with mannitol when compared with water (*P*<.001 at all sites except ICJ; *P* = .006 at ICJ) or positive iodinated contrast (*P*<.001 across all sites). Our findings are similar to findings reported by Prakashini et al and Elamparidhi et al., who reported a significantly better luminal distension with mannitol when compared with water or positive iodinated contrast (*P*<.001 in both the studies) [1,2]. The mean luminal measurements at ileum and ileocecal junction in our study are similar to that observed by Wang et al., who reported mean ileal diameter of 2.15 ± 1.3 cm (mean ± SD)each at ileum and ileocecal junction with mannitol respectively, 1.01 ± 0.05 cm (mean ± SD) , 0.99 ± 0.06 cm (mean ± SD) at ileum and ileocecal junction respectively with water[53]. Prakashini et al., reported similar luminal diameters at the level of duodenum and jejunum, whereas there was greater luminal diameter in their study at ileum and ileocecal junction with mannitol, water and positive iodinated contrast when compared with our study (2.11 ± 0.25 cm, 1.62 ± 0. 23 cm and 1.71 ± 0.23 cm (mean ± SD) respectively at ileum and 1.42 ± 0.45 cm, 1.16 ± 0.36 cm and 1.34 ± 0.52 cm (mean ± SD) respectively at ileocecal junction)[2]. A similar finding was also reported by Elamparidhi et al., who reported the mean (± SD) luminal diameter of 3.8 ± 1.1 cm, 1.4 ± 0.3 cm and 2 ± 0.5 cm at ileum with mannitol, water and positive iodinated contrast and mean (± SD) luminal diameter of 3.9 ± 0.9 cm, 1.9 ± 0.5 cm and 2.6 ± 0.5 cm at ileocecal junction with mannitol, water and positive iodinated contrast. The authors also reported greater luminal diameters at all levels (duodenum and jejunum) when compared with our study[1] or Prakashini et al study[2]. The differences could be attributed to the sites of measurements, as we had taken measurements at slightly different ileal sites compared to other studies[1,2].

Qualitative evaluation was performed to assess the bowel loops for adequate distension or homogeneity of luminal contents or fold visibility and also to assess mural fold characteristics. The degree of bowel distension or homogeneity of luminal contents / fold visibility was significantly better with mannitol, when compared with water or positive iodinated contrast (P<.001). Water was the least effective agent in achieving adequate bowel distension or homogeneity of luminal contents. The degree of mural fold visibility was significantly better with mannitol when compared with water or positive iodinated contrast (P<.001). Additionally, water showed better mural fold visibility when compared with positive iodinated contrast (P<.05). Overall, mannitol showed better bowel distension or homogeneity of luminal contents and mural fold visibility, when compared with water and positive iodinated contrast. Water showed better mural fold visibility when compared with positive iodinated contrast, while positive iodinated contrast showed better bowel distension or homogeneity of luminal contents.

Better luminal distention and homogenous attenuation was achieved by mannitol owing to its osmotic property which is minimal in positive contrast and water. The rapid absorption of water by bowel mucosa[2], can be attributed to its poor performance in providing adequate bowel distension or homogeneity of luminal contents / fold visibility. Positive iodinated contrast agents are also known to have small osmotic effect, which explains its better performance in demonstrating adequate bowel distension or homogeneity of luminal contents / fold visibility, when compared with water. The osmolality of mannitol is higher than positive iodinated contrast, therefore providing better performance in demonstrating bowel distension or homogeneity of luminal contents / fold visibility[1]. In patients who had

positive iodinated contrast, the intraluminal and mural density was similar resulting in reduced conspicuity of mural enhancement[2].

The use of positive iodinated contrast results in high density of luminal contents, which can often blur the distinction between bowel and luminal contents. Other factors responsible for poor bowel wall demonstration with positive contrast are high density of contrast potentially causing artifacts and partial volume averaging (less likely with iodinated contrast)[1,2]. Multiple artifacts may also be present due to differential attenuation resulting in increased concentration in some areas[56].This finding is of paramount importance when it comes to diagnosing inflammatory and ischemic conditions of the bowel, where mural characterization is very important[2].

In our study, the visualization of distal ileum and ileocaecal junction was excellent with mannitol and poor with water. This is important in evaluation of bowel pathologies, as many infective and neoplastic pathologies have predisposition to the ileocaecal junction. Hence, its optimal distension and homogeneity are very essential. While use of water may not cause adequate distension of these areas, use of positive iodinated contrast can obscure the mural enhancement features, which make it difficult to accurately assess these regions[1,2]. Mannitol overcomes these limitations and therefore can be considered superior in evaluation of small bowel pathologies, especially in distal ileum and ileocaecal junction.

However, there are some demerits of neutral oral contrast agents such as mannitol and water. In cases of perforation, fistulae or suspected anastomotic leak, neutral oral contrast

agents do not give any additional information and in such a scenario positive oral contrast is employed. Also, certain cystic lesions of the mesentery or the pelvis cannot be differentiated from bowel lesions when neutral oral contrast is given. Hence, in such cases oral positive iodinated contrast may be useful[1]. Another limitation of neutral contrast agent is differentiating it from cystic tumours and abdominal collection. Use of intravenous contrast enhances bowel wall helping differentiate these lesions[2].

In our study, the degree of large bowel distension was significantly better with mannitol when compared with water or positive iodinated contrast (P<.001). Similarly, positive iodinated contrast showed significantly better large bowel distension when compared with water (P<.05).

In our study, mannitol showed good large bowel distension in 60% with average distension in 16.67% and poor distension in 23.33% of patients. Our results are similar to Prakashini et al., who reported that 61 % of patients in the mannitol group showed excellent distention of large bowel, 26 % showed good distension and rest showed fair distension of the large bowel[2].

In assessment of the large bowel, features like haustral pattern visibility and enhancement was compared in all the three groups and it was best in mannitol followed by positive contrast and water. The degree of large bowel distension usually depends on the amount and well as the duration of consumption of contrast. It also depends on patient factors such pace of small bowel propulsive peristalsis and the rate at which the contrast was

consumed. Mannitol has rapid transit time and is non-absorbable, properties which are probably responsible for filling of large colon and thus provide excellent distension and evaluation of large bowel. This could help differentiate diseases such as Crohn's disease and ileocecal tuberculosis, which are common in our setup[2].

The patients who received mannitol had no major side effects post its intake. Few of them had increased frequency of stools. However, no signs of dehydration were reported. Similar findings have been observed by authors in previous literature, and such subtle discomfort should not be considered as the determining factor for the usage of mannitol[1,2].

Our study has certain limitations. One was a relatively smaller sample size, which could have introduced certain age and gender bias. However, our sample was similar in terms of age and gender distribution, thereby reducing this bias. Secondly, the bowel distension was taken at fixed levels, which at best can be considered as a surrogate marker and may not be representative of the whole bowel. Unfortunately, we did not have a software, which could map the whole bowel. We believe that measuring bowel distension at specific sites is an equally good method to assess bowel distension. Thirdly, our study was not completely blinded as patients having positive iodinated contrast can be identified and this may result in some reporting bias. Lastly, our results may also be affected by the patient behavior of drinking mannitol, water or positive iodinated contrast. This bias was reduced by directly observing the patients during the whole time of study. However, in an everyday scenario we may not be able to monitor the patients regarding the intake of oral contrast.

In this study, three oral contrast agents were compared out of which two were neutral (water and mannitol) and positive iodinated contrast agent. We found that distension and various mural characteristics amongst the three groups, was best with mannitol.

CONCLUSION

Adequate luminal distension of bowel loops is critical in evaluation of bowel pathologies. We observed that small bowel distension was excellent with mannitol followed by positive oral contrast and least by water. Mannitol showed better bowel distension or homogeneity of luminal contents / fold visibility and mural fold visibility, when compared with water and positive iodinated contrast. Water showed better mural fold visibility when compared with positive iodinated contrast, while positive iodinated contrast showed better bowel distension or homogeneity of luminal contents. Additionally, large bowel distension was significantly better with mannitol when compared with water or positive iodinated contrast.

We recommend that mannitol should be employed on routine basis for CECT abdomen study irrespective of the indication as it is superior to both water and positive oral contrast in evaluation of bowel loops.

SUMMARY

Small bowel is a challenging area for the surgeon and the gastroenterologist because of its long length and vague symptomatology, often making the radiologist an essential part of the diagnostic team. Ultrasound is less sensitive for evaluating bowel due to bowel gas artifacts. CT has good spatial and contrast resolution and is considered a better modality for the evaluation of bowel pathologies. Mannitol has high osmolarity and therefore it is hypothesized to provide better distension of bowel loops. There is paucity of data on what actually constitutes an ideal oral contrast agent. This study was taken up to demonstrate if bowel distension and enhancement pattern on MDCT is better visualised with mannitol in comparison with water and iodinated oral contrast, thus helping in optimal bowel evaluation.

The aims and objectives of the study were to perform contrast enhanced CT abdomen (CECT) with water, mannitol and iodinated positive contrast as oral contrast agent and to compare the distension and enhancement pattern of bowel with water, mannitol and iodinated contrast on CECT abdomen.

This was a hospital based observational study performed on 90 patients referred for CECT abdomen with extra-intestinal pathologies at the Department of Radiodiagnosis , R. L. Jalappa Hospital and Research Centre attached to Sri Devaraj Urs medical college, Kolar. Informed consent was taken from individuals for their willingness to participate in the study. Baseline data were collected from the patients along with pertinent clinical history and relevant lab investigations. Individuals were randomly divided into three groups and were

given either 1500 mL of plain water (Group 1), 1500 mL of 3% mannitol (Group 2), or iodinated oral contrast (15 mL in 1500 mL) (Group 3), 45 minutes to one hour prior to the CT scan. They underwent unenhanced CT study followed by contrast enhanced CT study with standard protocol using 16-slice Siemens® Somatom Emotion® scanner. The study included patients aged 18 years or over undergoing CECT abdomen for extra-intestinal pathologies. Patients who are allergic to intravenous contrast, patients with deranged renal function tests and pregnant patients were excluded.

Analysis of the images was done by two radiologists who were blinded to the neutral luminal contrast agents, i.e., Mannitol and water. The radiologists were aware of the clinical question for the study and had access to patient's files, results of other imaging tests (such as ultrasound and X-rays) and results of any previous studies in the same patient. The radiologists had 10 years and 5 years of experience in cross sectional imaging. Quantitative and qualitative evaluation of bowel distension was done using CECT abdomen images. The values and findings of both radiologists were compared and mean values were acquired at each anatomical level.

Qualitative and quantitative bowel analysis for distension, mural fold visualization, enhancement and overall image quality was analyzed by diameter measurement and point scale system at at different anatomical levels, which included duodenum, jejunum, ileum and lastly ileocecal junction. Qualitative examination of bowel loops was done in the three groups by using a continuous 4-point scale (0-3, fair to excellent, percentage of small bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility).

1. Score 0-Fair (<25%)
2. Score 1-Good (25-50%)
3. Score 2 Very good (50-75 %)
4. Score 3- Excellent (>75%)

The score was given based on the percentage of bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility. A score of 0 indicated <25% of bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility and score of 3 indicated >75% of bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility.

Data was entered into Microsoft excel data sheet and was analyzed using SPSS 22 version software. Categorical data was represented in the form of frequencies and proportions. Chi-square test was used as test of significance for qualitative data and ANOVA test was used as test of significance for quantitative data. *p* value <0.05 was considered as statistically significant.

We included 90 patients in our study who were randomly distributed into three groups (n = 30 in each group). The mean age of patients in Group 1 (Water) was 51 ± 11.86 years (mean ± SD), Group 2 (Mannitol) was 44.43 ± 14.92 years (mean ± SD) and Group 3 (positive iodinated contrast) was 45.5 ± 16.87 (mean ± SD). There was no significant difference between the age group of patients in either of the groups (*P* = .18; not significant). Total mean age was 46.9 ± 14 years with range of 18-75 years. Out of 90 cases, there were

total 45 males and 45 females with no significant difference between gender distribution across the three groups.

The mean distension at duodenum was 1.89 ± 0.33 cm (mean ± SD) with water, 2.28 ± 0.36 cm (mean ± SD) with mannitol, and 2.01 ± 0.33 cm (mean ± SD) with positive oral contrast. Overall, maximum luminal distension was seen at the level of duodenum followed by J1 site (at the level of origin of SMA) across all the groups (irrespective of type of contrast). The least luminal distension was seen at the level of ileocecal junction across all subgroups. Among all the groups, maximal luminal distension was seen in the mannitol group, irrespective of the site. Overall, there was significantly better luminal distension with mannitol when compared with water (P<.001 at all sites except ICJ; P = .006 at ICJ) or positive iodinated contrast (P<.001 across all sites). The luminal distension provided by water and positive iodinated contrast was similar with no statistically significant difference among these groups at all sites.

Qualitative evaluation was performed to assess the bowel loops for adequate distension or homogeneity of luminal contents or fold visibility. It can be seen that 60% of patients using mannitol showed excellent bowel distension or homogeneity of luminal contents or fold visibility and only 10% of patients who had water as oral contrast showed excellent distension. Furthermore, nearly half of patients who had water as oral contrast showed only good score (grade 1) and nearly half of patients who used positive iodinated contrast reported a very good score. The degree of bowel distension or homogeneity of luminal contents was significantly better with mannitol, when compared with water or positive iodinated contrast (P<.001) and degree of bowel distension or homogeneity of

luminal contents was significantly better with positive iodinated contrast when compared with water ($P = .01$). Water was the least effective agent in achieving adequate bowel distension or homogeneity of luminal contents. Overall, mannitol showed better bowel distension or homogeneity of luminal contents followed by positive iodinated contrast and water.

The mural fold characteristics across all the groups were compared. Another scoring system was used where score 0 was given if the bowel loops were partially or completely collapsed with was poor mural fold visibility. Score 1 was given if mural fold visibility was good and score 2 when there was excellent mural fold visibility. Mannitol showed excellent mural fold visibility in more than 50% of cases (n = 17; 56.67%) and good mural fold visibility in another 11 patients (36.67%) and only two cases showed poor mural fold visibility. The degree of mural fold visibility was significantly better with mannitol when compared with water or positive iodinated contrast ($P<.001$). In contrast, water showed good or excellent mural fold visibility (scores 1 and 2) in 11 patients (36.67%) and poor mural fold visibility in 63.33% of cases (n = 19). Positive iodinated contrast showed poor mural fold visibility in 90% of the cases (n = 27). Water showed better mural fold visibility when compared with positive iodinated contrast ($P<.05$). Overall, mannitol showed better mural fold visibility followed by water and positive iodinated contrast.

Overall mannitol showed better bowel distension or homogeneity of luminal contents / fold visibility and mural fold visibility, when compared with water and positive iodinated contrast. Water showed better mural fold visibility when compared with positive iodinated

contrast, while positive iodinated contrast showed better bowel distension or homogeneity of luminal contents.

Qualitative assessment of bowel distension was performed at various levels like caecum, ascending colon, splenic flexure and transverse colon. Features like haustral visibility and degree of large bowel distension were graded as good, average and poor based on subjective assessment. Mannitol showed good large bowel distension in 18 cases (n = 60%) with average distension in 5 patients (16.67%) and poor distension in seven patients (23.33%). None of the patients who had water showed good large bowel distension with majority of patients showing poor large bowel distension (n = 19; 63.3%) and remaining 11 patients showing average large bowel distension (36.7%). Patients who received positive iodinated contrast showed average large bowel distension in 19 cases (63.33%), poor large bowel distension in seven cases (23.33%) and good large bowel distension in four cases (13.34%). Degree of large bowel distension was significantly better with mannitol when compared with water or positive iodinated contrast ($P<.001$). Similarly, positive iodinated contrast showed significantly better large bowel distension when compared with water ($P<.05$).

Small bowel distension was excellent with mannitol followed by positive oral contrast and least by water. Mural characteristics and enhancement pattern were better with mannitol as compared with water and positive oral contrast. We concluded that mannitol should be employed on routine basis for CECT abdomen study irrespective of the indication, helping by laying emphasis on the bowel distension and mural characterization.

BIBLIOGRAPHY

1 Elamparidhi P, Sivaranjanie S, Kumar RR, Sibhithran R, Kumar AA. Comparison of water, mannitol and positive oral contrast for evaluation of bowel by computed tomography. Int J Anat Radiol Surg 2017;6:RO13-7.

2 Prakashini K, Kakkar C, Sambhaji C, Shetty CM, Rao VR. Quantitative and qualitative bowel analysis using mannitol, water and iodine-based endoluminal contrast agent on 64-row detector CT. Indian J Radiol Imaging 2013;23:373-8.

3 Soyer P, Boudiaf M, Fishman EK, Hoeffel C, Dray X, Manfredi R, et al. Imaging of malignant neoplasms of the mesenteric small bowel: New trends and perspectives. Crit Rev Oncol Hematol 2011;80:10-30.

4 Zhang LH, Zhang SZ, Hu HJ, Gao M, Zhang M, Cao Q, et al. Multi-detector CT enterography with iso-osmotic mannitol as oral contrast for detecting small bowel disease. World J Gastroenterol 2005;11:2324-9

5 Goto A, Sumiyama K, Kamioka Y, Nakasyo E, Ito K, Iwasaki M, et al GDNF and endothelin 3 regulate migration of enteric neural crest-derived cells via protein kinase A and Rac1. J Neurosci 2013;33:4901-12.

6 Soffers JH, Hikspoors JP, Mekonen HK, Koehler SE, Lamers WH. The growth pattern of the human intestine and its mesentery. BMC Dev Biol 2015;15-31.

7 Nagy N, Goldstein AM. Enteric nervous system development: A crest cell's journey from neural tube to colon. Semin Cell Dev Biol 2017;66:94–106.

8 Gut development [internet]. cited 2019 Oct 28 [updated 2015 Oct 13]. Available from: https://web.duke.edu/anatomy/embryology/gi/gi.html.

9 Saha M. Alimentary Tract Atresias associated with Anorectal Malformations: 10 Years' Experience. J Neonatal Surg 2016;5:43.

10 Gourevitch A. Duodenal atresia in the newborn. Ann R Coll Surg Engl 1971;48:141–58.

11 Tackett JJ, Muise ED, Cowles RA. Malrotation: Current strategies navigating the radiologic diagnosis of a surgical emergency. World J Radiol 2014;6:730–6.

12 Gray SW, Colborn GL, Pemberton LB, Shandalakis LJ, Shandalakis JE. The duodenum. I. Anatomy and development. Am Surg 1989;55:257-61.

13 Guo ZJ, Chen YF, Zhang YH et-al. CT virtual endoscopy of the ampulla of Vater: preliminary report. Abdom Imaging 2011;36:514-9.

14 Anatomy of the lower digestive tract. In: Rogers K, editor. The Human body. The digestive system. 1st edition. Chapter 3. Britannica Educational Publising. New York:NW. 2011. Page 61-73.

15 Small intestine. In: Strandring S, editor. Gray's Anatomy. The anatomical basis of clinical practice. 40th edition. Chapter 66. Churchill Livingstone Elsevier. 2008.p 1124-35.

16 Kiela PR, Ghishan FK. Physiology of intestinal absorption and secretion. Best Pract Res Clin Gastroenterol 2016; 30:145–59.

17 Crohn, B. B., & Yarnis, H. The Anatomical Position of the Ileum in Health and Disease. Radiology 1939; 33:325–30.

18Teitelbaum EN, Vaziri K, Zettervall S, Amdur RL,Orkin BA.Intraoperative small bowel length measurements and analysis of demographic predictors of increased length. Clinical Anatomy 2013;26:827-32.

19 Jeppesen PB, Mortensen PB. Enhancing bowel adaptation in short bowel syndrome. Curr gastroenterol rep. 2002;4:338-47.

20 Jeppesen PB. Short bowel syndrome–characterisation of an orphan condition with many phenotypes. Expert Opinion on Orphan Drugs. 2013;1:515-25.

21 Conley D, Hurst PR, Stringer MD An investigation of human jejunal and ileal arteries. Anat Sci Int 2010;85:23–30.

22 Van Kruiningen HJ, West AB, Freda BJ ,Holmes KA Distribution of Peyer's patches in the distal ileum. Inflamm Bowel Dis 2002;8:180–5.

23 Uppal K, Tubbs RS, Matusz P,Shaffer K, Loukas M. Meckel's diverticulum: a review. Clin Anat 2011;24:416–22.

24 Rubesin SE. Barium examinations of the small intestine. In: Gore RM, Levin MS, eds. Textbook of gastrointestinal radiology 4nd edition Philadelphia, Pa:Saunders, 2015; 665-7.

25 Silva A, Beaty S, Hara A, Fletcher J, Fidler J, Menias C et al. Spectrum of Normal and Abnormal CT Appearances of the Ileocecal Valve and Cecum with Endoscopic and Surgical Correlation. RadioGraphics 2007;27:1039-54.

26 Horton KM, Fishman EK. Volume-rendered 3D CT of the mesenteric vasculature: normal anatomy, anatomic variants, and pathologic conditions. Radiographics. 2002;22:161-72.

27 Morrison ID,McLaughlin P ,Maher MM. Current status of imaging of the gastrointestinal tract : Imaging techniques and radiation issues. In : Adam A, Dixon AK, Gillard JH, Schaefer-Prokop CM, editors. Grainger and Allisons Diagnostic Radiology,6th edition, Pa: Elsevier,2015; p.645-58.

28 Musson R, Bickle I, Vijay R. Gas patterns on plain abdominal radiographs: a pictorial review. Postgrad Med J 2011;87:274-87.

29 Pickhardt PJ. The peroral pneumocolon revisited: a valuable fluoroscopic and CT technique for ileocecal evaluation. Abdom Imaging 2011;37:313-25.

30 Cronin CG, Dowd G, Mhuircheartaigh JN, DeLappe E, Allen RH, Roche C et al. Hypotonic MR duodenography with water ingestion alone: feasibility and technique. European Radiology 2009;19:1731-5.

31 Hara AK, Leighton JA, Sharma VK, Heigh RI, Fleischer DE. Imaging of Small Bowel Disease: Comparison of Capsule Endoscopy, Standard Endoscopy, Barium Examination, and CT. RadioGraphics 2005;25:697-711.

32 Costamagna G, Shah SK, Riccioni ME, Foschia F, Mutignani M, Perri V, et al. A prospective trial comparing small bowel radiographs and video capsule endoscopy for suspected small bowel disease. Gastroenterology 2002;123:999-1005.

33 Sreeram E. Computed tomography: Physical principles, Clinical applications and Quality control. 2nd ed. Philadelphia PA. W B Saunders 2001.p1-28.

34 Goldman LW. Principles of CT and CT technology*. J Nucl Med Technol 2007; 35:115–28.

35 Hong S, Kim A, Byun J, Won H, Kim P, Lee M, et al. MDCT of small-bowel disease value of 3D imaging. Am J Roentgenol 2006;187:1212–21.

36 Sheikh MT, Sheikh MT, Jan M, Khan HA, Vashisht GP, Wani ML. Role of Multi-Detector CT (MDCT) in Evaluation of Bowel Diseases. J Clin Diagn Res 2017;11:TC11-13.

37 Fernandes T, Oliveira MI, Castro R, Araújo B, Viamonte B, Cunha R. Bowel wall thickening at CT: simplifying the diagnosis. Insights Imaging 2014;5:195-208.

38 Wittenberg J, Harisinghani MG, Jhaveri K, Varghese J, Mueller PR. Algorithmic approach to CT diagnosis of the abnormal bowel wall. Radiographics 2002;22:1093-107.

39 Macari M, Megibow AJ, Balthazar EJ. A pattern approach to the abnormal small bowel: observations at MDCT and CT enterography. Am J Roentgenol 2007;188:1344-55.

40 Furukawa A, Saotome T, Yamasaki M, Maeda K, Nitta N, Takahashi M, et al. Cross-sectional imaging in Crohn disease. Radiographics 2004;24:689-702.

41 Elsayes KM, Al-Hawary MM, Jagdish J, Ganesh HS, Platt JF.CT enterography: principles, trends, and interpretation of findings. Radiographics. 2010;30:1955-70.

42 Rocha EL, Pedrassa BC, Bormann RL, Kierszenbaum ML, Torres LR, D'Ippolito G. Abdominal tuberculosis: a radiological review with emphasis on computed tomography and magnetic resonance imaging findings. Radiol Bras 2015;48:181-91.

43 Minordi LM, Binda C, Scaldaferri F, Holleran G, Larosa L, Belmonte G, edi R. Primary neoplasms of the small bowel at CT: a pictorial essay for the clinician. Eur Rev Med Pharmacol Sci. 2018 Feb 1;22:598-608.

44 El-Kalioubie M, Ali R. Abdominal CT enterography as an imaging tool for chronic diarrhea: Review of technique and diagnostic criteria. The Egyptian Journal of Radiology and Nuclear Medicine. 2015;46:275-86.

45 Winklhofer S, Lin WC, Wang ZJ, Behr SC, Westphalen AC, Yeh BM. Comparison of Positive Oral Contrast Agents for Abdominopelvic CT. Am J Roentgenol 2019;212:1037-43.

46 Harisinghani MG, Wittenberg J, Lee W, Chen S, Gutierrez AL, Mueller PR. Bowel wall fat halo sign in patients without intestinal disease. Am J Roentgenol 2003;181:781-4.

47 Masselli G, Gualdi G. CT and MR enterography in evaluating small bowel diseases: when to use which modality? Abdominal imaging 2013;38:249-59.

48 Mannitol. National Center for Biotechnology Information. PubChem Database [internet]. Accessed 2019 Oct 29. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Mannitol.

49 Ros PR, Ji H. Special focus session: multisection (multidetector) CT: applications in the abdomen. Radiographics 2002;22:697-700.

50 Wong J, Moore H, Roger M, McKee C. CT enterography: Mannitol versus VoLumen. J Med Imaging Radiat Oncol 2016;60:593-8.

51 Wang YR, Yu XL, Peng ZY. Evaluation of different small bowel contrast agents by multi-detector row CT. Int J Clin Exp Med 2015;8:16175.

52 Berther R, Patak MA, Eckhardt B, Erturk SM, Zollikofer CL. Comparison of neutral oral contrast versus positive oral contrast medium in abdominal multidetector CT. Eur Radiol. 2008;18:1902-9.

53 Wang YR, Yu XL, Peng ZY. Evaluation of different small bowel contrast agents by multi - detector row CT. Int J Clin Exp Med. 2015;8:16175-82.

54 Hashemi J, Davoudi Y, Taghavi M, Pezeshki Rad M, Moghadam AM. Improvement of distension and mural visualization of bowel loops using neutral oral contrasts in abdominal computed tomography. World J Radiol 2014;6:907-12.

55 Meindl TM, Hagl E, Reiser MF, Mueller-Lisse UG. Comparison of 2 different protocols for ingestion of low-attenuating oral contrast agent for multidetector computed tomography of the abdomen. J Comput Assist Tomogr 2007;31:218-22.

56 Callahan MJ, Talmadge JM, MacDougall R, Buonomo C, Taylor GA. The use of enteric contrast media for diagnostic CT, MRI, and ultrasound in infants and children: a practical approach. Am J Roentgenol 2016;206:973-9.

ANNEXURE I

PROFORMA

COMPARISON OF MANNITOL, WATER AND IODINE BASED ORAL CONTRAST IN EVALUATION OF BOWEL BY MULTI-DETECTOR COMPUTED TOMOGRAPHY

Demographic details:

Study ID:

-Name:

-Age:

-Address:

Clinical History:

Relevant investigations

Clinical diagnosis:

CT findings :

Bowel distention at	Water	Mannitol	Positive oral contrast
Duodenum (D1)			
Duodenum (D2)			
Proximal jejunum (J1)			
Distal jejunum (J2)			
Ileum (I1)			
Ileum (I2)			
Ileocecal junction			

Comments –

4 point scale score: (Tick one)

(Based on percentage of small bowel loops showing adequate distension or homogeneity of luminal contents or fold visibility)

Grading: (Please check one)

1. Score 0-Fair (<25%) ☐
2. Score 1-Good (25-50%) ☐
3. Score 2 Very good (50-75 %) ☐
4. Score 3- Excellent (>75%) ☐

Qualitative scale for mural fold visibility grading:

Grading: (Please check one)

1. Score 0 – bowel loops are partially or completely collapsed with was poor mural fold visibility ☐
2. Score 1 – mural fold visibility is good ☐
3. Score 2 – excellent mural fold visibility ☐

Qualitative assessment of bowel distension

(Subjective visualization of caecum, ascending colon, splenic flexure and transverse colon and include features like haustral visibility and degree of large bowel distension)

Grading: (Please check one)

1. Good ☐
2. Average ☐
3. Poor ☐

Radiologist 1:

Radiologist 2:

ANNEXURE II

INFORMED CONSENT

STUDY TITLE: COMPARISON OF MANNITOL, WATER AND IODINE BASED ORAL CONTRAST IN EVALUATION OF BOWEL BY MULTI-DETECTOR COMPUTED TOMOGRAPHY

CHIEF RESEARCHER/ PG GUIDE'S NAME: Dr. RACHEGOWDA N.

PRINCIPAL INVESTIGATOR: Dr. THATI SAI SOUMYA

NAME OF THE SUBJECT:

AGE :

GENDER :

a. I have been informed in my own language that this study involves CT and use of contrast material as part of procedure. I have been explained thoroughly and understand its complication and possible side effects.

b. I understand that the medical information produced by this study will become part of institutional record and will be kept confidential by the said institute.

c. I understand that my participation is voluntary and may refuse to participate or may withdraw my consent and discontinue participation at any time without prejudice to my present or future care at this institution.

d. I agree not to restrict the use of any data or results that arise from this study provided such a use is only for scientific purpose(s).

e. I confirm that _____ (chief researcher/ name of PG guide) has explained to me the purpose of research and the study procedure that I will undergo and the possible risks and discomforts that i may experience, in my own language. I hereby agree to give valid consent to participate as a subject in this research project.

Participant’s signature/thumb impression

Signature of the witness: Date:

1)

2)

I have explained to _____ (subject) the purpose of the research, the possible risk and benefits to the best of my ability.

Chief Researcher/ Guide signature

Patient Information Sheet

TITLE: COMPARISON OF MANNITOL, WATER AND IODINE BASED ORAL CONTRAST IN EVALUATION OF BOWEL BY MULTI-DETECTOR COMPUTED TOMOGRAPHY

Principal Investigator: Dr. THATI SAI SOUMYA / Dr. RACHEGOWDA N.

I, Dr. THATI SAI SOUMYA, post-graduate student in Department of Radio-Diagnosis at Sri Devaraj Urs Medical College. I will be conducting a study titled “Comparison of mannitol, water and iodine based oral contrast in evaluation of bowel by multi-detector computed tomography” for my dissertation under the guidance of Dr. Rachegowda N, Professor and Head, Department of Radio-Diagnosis. In this study, you will be given 1500 ml of oral contrast and then you will undergo CT scan for assessment of bowel. You will not be paid any financial compensation for participating in this research project.

All of your personal data will be kept confidential and will be used only for research purpose by this institution. You are free to participate in the study. You can also withdraw from the study at any point of time without giving any reasons whatsoever. Your refusal to participate will not prejudice you to any present or future care at this institution

Name and Signature of the Principal Investigator

Date

ANNEXURE III

Master Chart – Comparison of mannitol, water and, iodine based oral contrast in evaluation of bowel by multidetector computed tomography

Abbreviations

A - average

D – duodenum

F – female

G - good

I1 – ileum site 1

I2 – ileum site 2

ICJ – ileocecal junction

J1 – jejunum site 1

J2 – jejunum site 2

LBD – large bowel distension

M – male

MFV – mural fold visualization

MN – mannitol

P – Poor

PIC – positive iodinated contrast

W - water

Masterchart – Comparison of mannitol, water and, iodine based oral contrast in evaluation of bowel by multidetector computed tomography

Sl. No	Study ID	Age (in years)	Gender	Type of contrast	Mean quantitative measurement (in cm)						4 point scale score	MFV	LBD
					D	J1	J2	I1	I2	ICJ			
1	516203	26	F	MN	2.6	2.1	2.7	1.8	2	1.5	3	1	A
2	770552	23	F	MN	2.8	2.2	2	2	2.7	1.7	3	2	G
3	783836	56	M	MN	2.4	2.5	2.6	1.6	2.4	1.4	3	2	G
4	794291	75	M	MN	2.1	2.8	2.5	1.6	1.8	1	3	2	G
5	127935	36	F	MN	1.8	2.1	2.5	2.5	1.8	1.4	3	2	G
6	874997	21	F	MN	2.6	2.4	2.5	2	1.8	1.4	3	2	G
7	606002	60	M	MN	1.8	2.5	2.2	2.1	1.7	0.9	3	1	A
8	442280	40	F	MN	2.2	2.7	2.7	2.3	2.2	1.7	2	1	P
9	378955	55	F	MN	2.5	2.2	2.2	2.2	2	1	3	2	G
10	316927	40	F	MN	2	2.5	2.4	2.2	2.1	1.1	2	1	P
11	729859	60	M	MN	2.9	2.4	2.3	2.2	2.1	1.1	3	2	G
12	858625	40	F	MN	1.9	2.4	2.4	2.2	1.8	1.3	2	1	P
13	749507	53	F	MN	2.4	2	1.9	2	2	1	3	2	G
14	610365	35	F	MN	2.6	2.4	2.3	2	1.9	1.1	2	1	A
15	860290	36	M	MN	2.6	1.8	1.7	1.8	1.5	1	3	2	G
16	465771	50	F	MN	2.2	2.8	2.5	2	1.7	1.1	2	1	G
17	108422	54	F	MN	1.9	1.8	1.8	1.5	1.5	0.9	0	0	P
18	14838	35	F	MN	2.4	2	1.8	1.8	1.8	1	2	1	A
19	835624	28	M	MN	2.5	1.7	1.6	1.8	1.7	1	2	1	P

A – average; D – duodenum; F – female; G – good; I1 – ileum site 1; I2 – ileum site 2; ICJ – ileocecal junction; J1 – jejunum site 1; J2 – jejunum site 2; LBD – large bowel distension; M – male; MFV – mural fold visualization; MN – mannitol; P – poor; PIC – positive iodinated contrast; W - water

Masterchart – Comparison of mannitol, water and, iodine based oral contrast in evaluation of bowel by multidetector computed tomography

Sl. No	Study ID	Age (in years)	Gender	Type of contrast	Mean quantitative measurement (in cm)						4 point scale score	MFV	LBD
					D	J1	J2	I1	I2	ICJ			
20	663438	46	F	MN	1.9	1.5	1.4	1.2	1.2	1	1	1	G
21	452051	35	M	MN	2.2	2.3	2.2	1.7	1.8	1	3	2	G
22	260850	28	F	MN	2.2	2.3	2.2	1.9	1.8	1.1	3	2	G
23	634288	69	M	MN	2.5	2.3	2.4	2	2	1.2	3	2	G
24	504105	25	M	MN	2.2	2.7	2.7	2.3	2.2	1.7	3	2	G
25	824438	50	M	MN	2.5	2.2	2.2	2.2	2	1	3	2	G
26	499351	75	F	MN	2	2.5	2.4	2.2	2.1	1.1	2	1	P
27	924740	42	F	MN	2.5	1.7	1.6	1.8	1.7	1	3	2	G
28	168963	36	M	MN	1.9	1.5	1.4	1.2	1.2	1	1	0	P
29	707384	45	F	MN	1.9	2	1.9	1.6	1.5	1	1	2	A
30	851998	59	M	MN	2.4	2.5	2.6	2	2.1	1.3	3	2	G
31	800215	60	M	W	2	1.7	1.6	1.2	1.2	1	1	0	P
32	243946	35	M	W	1.8	2	1.9	1.6	1.6	1.2	3	1	A
33	344310	66	F	W	1.7	2	1.9	1.2	1.2	0.9	1	2	A
34	393583	65	M	W	1	1.6	1.4	1.3	1.5	0.9	0	0	P
35	313198	61	F	W	1.9	1.6	1.6	0.9	1	0.9	0	0	P
36	208385	30	M	W	1.8	1.8	1.7	0.9	1	0.8	0	0	P
37	491556	52	M	W	2.5	1.8	1.5	1.5	1.2	1.2	1	0	P
38	787596	43	M	W	2.4	1.8	1.7	1.2	1.2	0.7	1	1	A

A – average; D – duodenum; F – female; G – good; I1 – ileum site 1; I2 – ileum site 2; ICJ – ileocecal junction; J1 – jejunum site 1; J2 – jejunum site 2; LBD – large bowel distension; M – male; MFV – mural fold visualization; MN – mannitol; P – poor; PIC – positive iodinated contrast; W - water

Masterchart – Comparison of mannitol, water and, iodine based oral contrast in evaluation of bowel by multidetector computed tomography

Sl. No	Study ID	Age (in years)	Gender	Type of contrast	Mean quantitative measurement (in cm)						4 point scale score	MFV	LBD
					D	J1	J2	I1	I2	ICJ			
39	407887	66	F	W	1.6	1.9	1.5	1.6	1.5	0.9	0	0	P
40	553417	45	M	W	1.9	2.1	2.2	1.5	1.5	0.9	1	1	A
41	848810	68	M	W	2.5	1.6	1.7	1.7	1.6	1.1	2	0	A
42	999352	38	M	W	2.1	2.6	2.5	2.4	2.2	1	3	2	P
43	185461	65	F	W	2.3	2	1.9	1.7	1.6	1.6	1	0	P
44	248510	52	M	W	1.8	2.1	1.8	1.7	1.6	1.4	3	2	P
45	66906	60	M	W	1.7	2.3	1.7	1.9	1.8	1.2	2	0	P
46	731248	31	M	W	1.9	2	1.5	1.6	1.5	0.7	2	1	A
47	956128	50	F	W	2.4	2	1.6	1.2	1.2	1	1	1	A
48	364715	43	F	W	2.4	1.6	1.5	1.2	1.2	0.9	0	0	P
49	718012	36	F	W	1.5	1.2	1.1	1.1	1	0.8	0	0	P
50	695251	60	M	W	1.6	1.6	1.5	1.4	1.4	0.9	1	0	P
51	12129	41	F	W	1.7	1.5	1.3	1.2	1.3	0.8	0	0	P
52	351314	60	F	W	1.9	2.1	2.2	1.5	1.5	0.9	1	0	P
53	138297	70	F	W	1.8	1.7	1.8	1.7	1.6	1.4	0	0	P
54	719392	52	F	W	1.7	2.3	1.7	1.9	1.8	1.2	1	1	A
55	755812	40	M	W	1.8	2.2	2.1	2.1	2.2	1.1	2	1	A
56	801276	38	M	W	1.9	1.8	1.8	1.5	1.5	0.9	1	0	A
57	510712	47	F	W	2	1.5	1.4	1.3	1.4	0.9	1	0	P

A – average; D – duodenum; F – female; G – good; I1 – ileum site 1; I2 – ileum site 2; ICJ – ileocecal junction; J1 – jejunum site 1; J2 – jejunum site 2; LBD – large bowel distension; M – male; MFV – mural fold visualization; MN – mannitol; P – poor; PIC – positive iodinated contrast; W - water

Masterchart – Comparison of mannitol, water and, iodine based oral contrast in evaluation of bowel by multidetector computed tomography

Sl. No	Study ID	Age (in years)	Gender	Type of contrast	Mean quantitative measurement (in cm)						4 point scale score	MFV	LBD
					D	J1	J2	I1	I2	ICJ			
58	299249	60	F	W	1.8	1.7	1.7	1.6	1.6	1.2	2	1	A
59	243680	47	F	W	1.7	1.5	1.3	1.2	1.3	0.8	1	0	P
60	180308	50	F	W	1.5	1.4	1.4	1.3	1.2	0.9	1	0	P
61	116592	58	M	PIC	2.1	2.3	2.8	2	2.3	1.4	3	0	G
62	176143	65	F	PIC	2.2	1.4	1.3	1.1	1.2	0.9	3	0	G
63	964507	42	M	PIC	2.5	1.4	1.5	1.2	1.2	0.9	1	0	P
64	212786	30	M	PIC	2.8	1.4	1.6	1.2	1.2	0.9	0	0	P
65	708925	35	F	PIC	1.7	1.2	1	1.3	1.2	0.8	0	0	P
66	509634	44	M	PIC	1.8	1.7	1.5	1.3	1.2	1.7	1	0	A
67	830857	39	M	PIC	1.6	1.4	1.3	1.6	1.6	0.7	2	0	A
68	201498	60	M	PIC	2	1.8	1.7	1.6	1.7	1	3	0	G
69	773262	35	M	PIC	2.1	2.1	2.2	1.8	1.9	1	3	1	G
70	493777	85	M	PIC	1.8	1.8	1.7	1.5	1.5	0.8	2	0	A
71	452228	70	M	PIC	1.4	2	2.1	2	2	0.9	2	0	A
72	846075	26	M	PIC	1.6	1.6	1.7	1.3	1.3	0.9	2	0	A
73	557564	20	F	PIC	2	1.8	1.8	1.2	1.7	1.1	2	0	A
74	103067	45	F	PIC	2.1	1.5	1.5	1.6	1.5	0.9	2	0	A
75	847077	65	F	PIC	2.4	2	1.9	1.5	1.4	1	1	0	A
76	811318	30	M	PIC	2.2	2.4	2.3	2	1.9	1.2	3	0	A

A – average; D – duodenum; F – female; G – good; I1 – ileum site 1; I2 – ileum site 2; ICJ – ileocecal junction; J1 – jejunum site 1; J2 – jejunum site 2; LBD – large bowel distension; M – male; MFV – mural fold visualization; MN – mannitol; P – poor; PIC – positive iodinated contrast; W - water

Masterchart – Comparison of mannitol, water and, iodine based oral contrast in evaluation of bowel by multidetector computed tomography

Sl. No	Study ID	Age (in years)	Gender	Type of contrast	Mean quantitative measurement (in cm)						4 point scale score	MFV	LBD
					D	J1	J2	I1	I2	ICJ			
77	948680	27	F	PIC	1.6	1.7	1.8	1.3	1.7	0.9	1	0	A
78	628567	68	F	PIC	2.3	2.3	2.2	1.4	1.5	1	3	1	A
79	635519	36	M	PIC	2.3	2	2.1	2	1.8	0.8	2	0	A
80	253705	18	M	PIC	1.3	1.5	1.4	1.2	1.2	0.9	1	0	P
81	817804	55	M	PIC	1.9	1.9	2	1.2	1.1	0.6	2	0	A
82	955466	38	M	PIC	1.7	1.7	1.8	1.4	1.5	1.1	1	0	P
83	622662	60	M	PIC	2	1.5	1.5	1.6	1.6	0.8	2	0	A
84	7391	50	M	PIC	2.2	1.6	1.6	1.4	1.5	0.8	2	0	A
85	556549	60	M	PIC	2.2	1.6	1.5	1.3	1.4	1.2	2	0	A
86	218490	45	F	PIC	1.9	1.6	1.2	1.5	1.4	0.7	1	0	P
87	943647	27	F	PIC	2	1.8	1.7	1.6	1.6	0.9	1	0	P
88	335911	60	F	PIC	2.2	1.9	1.8	1.5	1.4	0.9	3	1	A
89	225472	45	F	PIC	2.2	1.7	1.8	1.5	1.4	0.8	2	0	A
90	158298	27	F	PIC	2.2	1.6	1.5	1.3	1.4	1.2	2	0	A

A – average; D – duodenum; F – female; G – good; I1 – ileum site 1; I2 – ileum site 2; ICJ – ileocecal junction; J1 – jejunum site 1; J2 – jejunum site 2; LBD – large bowel distension; M – male; MFV – mural fold visualization; MN – mannitol; P – poor; PIC – positive iodinated contrast; W - water