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REVIEW ARTICLE

Colonic transit studies: normal values for adults and children with comparison of radiological and scintigraphic methods

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Abstract The sitz or plastic marker study for colonic transit has been around for many years. It is applicable where an X-ray machine exists, is widely used and is accepted as the gold standard for diagnosing constipation. Recently, radiopharmaceutical methods have been developed. The theme of this review is their possible roles in the assessment of paediatric bowel motility disorders in patients presenting to paediatric surgeons. This review presents data on total and segmental transit in normal adults and children and comparing the two techniques in adults. Reliability and reproducibility are presented. Normative data for colonic transit in adults and children are discussed and parameters for assessing abnormal transit are reviewed. Normal colonic transit takes 20–56 h. Plastic marker studies are more readily accessible, but the assessment may be misleading with current methods. Plastic markers show faster transit than scintigraphy. It is difficult to compare the two techniques because methods of reporting are different. Using scintigraphy, repeatability is good. Separation of normal from slow transit in the ascending colon is apparent at 24 and 48 h, but the determination of transit through the distal colon/rectum in adults may require studies of more than 7 days. In conclusion, plastic marker studies and scintigraphy show similar transit rates in young adults and children. However, scintigraphy has advantages of allowing transit through the stomach and small intestine to be measured and has proved useful in the diagnostic workup of children with intractable constipation.

Keywords Slow transit constipation · Nuclear transit studies · Sitz markers · Scintigraphy · Paediatric constipation

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Introduction

More children present with constipation than any other gastrointestinal diagnosis [1]. 20% of these children have three or more medical visits and 11–20% have symptoms documented to last more than 1 month [1]. Constipation in young children is a poor prognostic sign with continued constipation through adolescence and into adulthood [2] and children who present before 5 years age are more likely to have continued symptoms and subsequent medical visits later in life [3]. Diagnostic methods are required to distinguish causes so that the correct treatment is instituted. Colonic dysmotility (abdominal pain, constipation, diarrhoea) is first evaluated by careful review of medical history, physical examination and laboratory studies to identify disorders that may produce chronic constipation symptoms [4–6]. Endoscopy or barium radiology may be performed to assess organic causes. When no organic cause is identified, patients are diagnosed as having a 'functional' bowel disorder [7]. Recently, GI transit studies have become an important part of the evaluation of patients with constipation [8–10].

Normal patterns of motility in the colon are highly variable [11]. The contents of a meal take 2–4 h to pass from the pylorus to the ileocolonic junction (500 cm) and 12–72 h to transit 100–150 cm of colon [7]. The velocity

of colonic transit is variable even in the normal population [12]. To evaluate motility through the GI tract, two techniques are used: transit of sitz (plastic) markers viewed by X-ray and transit of radioisotope viewed by gamma camera (scintigraphy) [7, 8]. Sitz markers have been used for longer and are widely available. The American Motility Society reviewed gastrointestinal transit studies in 2005 [9]. Their paper describes methods for studying gastric emptying, small bowel transit and colonic transit. They describe both radio-opaque markers and scintigraphy, summarising protocols, assessment, normal rates and abnormal patterns [9]. Radiological and radioisotope methods have provided quantitative data on total and regional colonic transit. Transit tests can also help to demonstrate the effect of medical or surgical treatments.

Plastic marker studies: sitz markers and X-rays

Measurement of colon transit using radio-opaque markers and X-rays was first described in 1969 [13], and has been widely used [14–17] to gain information about colorectal function in constipated patients for clinical management [17]. The markers are ingested with a meal and abdominal X-rays are obtained to count the number of markers in different segments of the colon. Most healthy adults pass all markers within 4–5 days [9]. Colonic distribution of markers may indicate colonic inertia, hindgut dysfunction or outlet obstruction. This method is widely used because it is simple, and clearly identifies patients with slow total transit times. It identifies abnormalities in transit and can be performed in a one-visit method [10]. Plastic marker studies are currently considered the gold standard for transit studies.

Normative data measured with the plastic marker method

Two main methods for plastic marker studies have developed:

1. Markers are ingested in a single dose and abdominal images obtained every 24 h until markers are no longer visible. This incurs exposure to radiation, is time consuming and inconvenient to the patient.
2. An identical number of markers (usually 10) are ingested on 3 consecutive days and an abdominal X-ray is obtained on day 4. Using this method, the physician can monitor the progress of markers over 72 h. This method is criticised because equilibrium between mean daily output of markers and marker input is not reached within 3 days. Equations are used to calculate segmental transit. Bone landmarks and clear bowel outlines are used to locate markers. The method can underestimate transit that takes more than 72 h. Another radiograph can be taken on day 7 [10, 17] or at 3-day intervals thereafter [9]. For a simple evaluation, colonic transit is normal in adults if <20% of markers can be seen on the X-ray after 120 h (day 5) [18], but much less than 20% would be normal for children.

Various approaches are reported to evaluate the progress of plastic markers [9, 13, 18–21]. The radiograph is divided into segments and the number of markers is multiplied by a factor to give the hours of transit.

Normative data in adults

Normative data for adult colonic transit measured with plastic markers from a range of studies [11, 19, 21–27] are listed in Table 1. Zaslavsky et al. [28] previously summarised data for normal adults. Stool frequency ranges from 3 to 11 per 7 days [21]. Radio-opaque markers progress regularly along the large bowel and transit times have been established for different segments (Table 2). The plastic marker technique was validated for the measurement of segmental transit in adults by Metcalf and colleagues [22] in the late 1980s. Similar results have been obtained for Asian and Caucasian populations [27, 29].

Gender effects

Studies that examined the effect of age, gender, reproducibility or constipation are shown in Table 3 [10, 24–26, 29–33]. Studies with large sample sizes show that women have slower gastric emptying [26, 34–36], slower small bowel transit [26, 37] and slower colonic transit [22, 26, 30, 38] than men. Transit rates are also slower in pregnancy [39–41], while postmenopausal women have faster gastric emptying [42, 43] and small bowel transit [26].

Reliability

To determine segmental transit, regions of interest (ROI) are drawn around bowel segments. It has been suggested that current methods may assign markers to incorrect bowel segments and this does not provide accurate data on transit through each colonic region [32]. Pomerri et al. [17] have shown that by ingesting barium on day 9 and taking an X-ray on day 11 the colon segments are easier to see and correct segmental marker count can be obtained. Inter-observer variability is reduced with this method. They found that rectosigmoid transit time was significantly overestimated in previous studies. They identified three subtypes: delay in the ascending colon, delay in the

Table 1 Adult normative values for gastrointestinal transit measured using plastic markers

Author	Reference	X-ray on day	*N*	Age range	CTT (h)				
					Mean	SD or range	Median	Upper 95th	UNL
Martelli 1978	[20]		114		59				<70
Arhan 1981	[19]		38		39	4			93
Metca1f 1987	[22]	4	24		35.8	2.5			<70
Chaussade 1989	[23]		91		34.4	16.2			67
Proano 1990	[11]		14	19–39	26	8.3			
Meir 1992	[24]		128	28–81	30 m				44 m
					41 f				70 f
Evans 1998	[25]		93	65–104			28.8		
Sadik 2003	[26]	7	40 m	18–70	31.2	16–46		55 m	
			43 f	19–61	36	24–89		106 f	
Chan 2004	[27]	4, 7	27 m	30–54	24.5	18.8			62.1
			24 f						
Mean					35.74				

UNL upper normal limit = mean ± 2 SD, *m* male, *f* female

descending colon and retention in the rectosigmoid [17]. Distal faecal impaction may cause nonpropagation or back-propagation of markers [17].

Preparation of the bowel may affect outlet obstruction more than slow colonic transit. Bergin [44] investigated the effect of clearing the bowel prior to a plastic marker study. 17/21 patients had slow transit in cleared and uncleared studies, while 4 patients with outlet obstruction showed no evidence of delayed transit after a cleanout [44].

Reproducibility

Two studies assessed reproducibility for plastic markers [17, 26] and show a very wide variation. For example, reproducibility was measured in 18 adults by Sadik et al. [26], and mean differences were −0.11 ± 1.2 h (mean ± SD) for gastric emptying, −0.06 ± 0.8 h for small bowel transit and 0.38 ± 0.78 days for colonic transit.

Normative data in children

The normal frequency of bowel movements at different ages has been defined [4] ranging from a mean of 4 per day at birth to 1.2 per day in children over 3 years. Values for total and segmental total colonic transit time (CTT) in children from six studies were summarised by Wagener et al. [45]. The CTT [19, 28, 45–48] (Table 4) and segmental transit times [19, 28, 45, 47–49] (Table 2) in children are similar to values in adults (Tables 1, 2). There are some variations in methods in different studies making regional comparisons difficult, e.g., X-rays on different days and the colon divided into different numbers of regions. Arhan et al. [19] directly compared adults and children and found that overall mean transit did not differ significantly in the large bowel between adults and children. Bautista Casasnovas et al. and Zaslavsky et al. [28, 47] studied normal adolescents and showed times similar to adults (Tables 3, 4). Paediatric studies examining effects of age, gender or constipation [28, 47–51] are listed in Table 5. Reproducibility has not been reported in paediatric studies.

Scintigraphy

Scintigraphy or radioisotope transit tests involve ingestion of a radioisotope and taking multiple images over up to 5 days. Gamma camera images are captured, ROI are drawn on the image and radioisotope counts in each region are measured. This method has been developed at a number of centres but is not readily available and is still considered a research tool [7, 8]. Some authors argue that it should now become the gold standard in transit studies. A number of variables must be considered when defining the normal range [52]. It is necessary to have an estimate of test reproducibility and intra-subject variability and to measure the effects of gender and age.

Comparison of results is limited by the use of different methods for delivery and analysis

Although the ranges of normal transit times in different studies are similar, they are not directly comparable because of different methods of delivery and assessment (Table 6). Isotope (technetium or indium) can be given orally in a non-absorbable form with a test meal [53], in a capsule coated with pH sensitive material that dissolves in the colon or terminal ileum [54], or in non-digestible

Table 2 Normative values (h) for segmental transit through the colon from plastic marker studies

Author	Reference	X-ray on day	*n*	Age range (years)	Asc col	UNL	Right colon	UNL	Trans col	UNL	Left colon	UNL	Desc col	UNL	Rect/sig	UNL	GITT
Adult																	
Arhan 1981	[19]	Daily	38				13.8	38			14.1	37			11	34	
Metcalf 1987	[22]		24				12.2 ± 1.3				11.2 ± 1.5				12.6 ± 1.4		
Abrahamsson 1988	[30]	7	56		31.2				16.8				55.2		31.2		112.8
Chaussade 1989	[23]		91				6.9 ± 7.8	20			9.1 ± 10.3	30			18.4 ± 12.5	44	
Proana 1990	[11]	1, 2, 5	14	19–39	9.9 ± 3.8												
Chan 2004	[27]	4, 7	51	30–54			5.8 ± 5.3	16			9.5 ± 10.8	31			9.2 ± 11.4	32	
Paediatric																	
Arhan 1981	[19]	Daily	23	2–15			7.7	18			8.7	20			12.4	34	
Bautista Casasnovas 1991	[47]	4	10	10–14			10.8 ± 3.5	17.8			12.2 ± 2.7	17.6			14.7 ± 2.1	19.1	
Zaslavsky 1998	[28]	4	13	12–18			6.7 ± 3.9	14.5			7.9 ± 7.8	23.5			15.6 ± 10.7		
Gutierrez 2002	[48]	7	22	2–14			7.25 ± 5.75	19.02			6.6 ± 6.2	19			14.96 ± 8.7		
Wagener 2004	[45]	7	22	4–15	5.5 ± 4.4	14.2			10.9 ± 9.6	33.1			6.1 ± 5.4	20.6	18.2 ± 13.3	40.8	
Park 2004	[49]	4	51	2–10			3.1 ± 4.2				5.1 ± 4.9				7.4 ± 4.9		
Scintigraphy																	
Tota 1998	[81]		15	3–14			5.4 ± 3.0	11.4			7.1 ± 3.4	13.9			9.8 ± 3.2	16.4	

UNL upper normal limit = mean ± 2 SD, *GITT* gastrointestinal transit time, *Asc col* ascending colon, *Trans col* transverse colon, *Desc col* descending colon, *Rect/sig* rectosigmoid colon

Table 3 Studies examining reproducibility or effects of age, gender or constipation in adults using plastic markers

Author	Reference	Reproducibility	Age	Gender	Constipation
Abrahamsson 1988	[30]			Y	Y
Turnbull 1989	[31]		Y	Y	Y
Ke 1990	[29]				Y
Meir 1992	[24]		Y	Y	
van der Sijp 1993	[32]		Y	Y	
Grotz 1994	[33]				Y
Evans 1998	[25]		Y	Y	Y
Sadik 2003	[26]	Y		Y	
Chan 2004	[27]		Y	Y	
Pomerri 2007	[17]	Y			Y
Sadik 2008	[10]		Y	Y	Y

capsules [55]. Delivery of isotope has also been via per-oral intubation of the caecum [56, 57], incorporated isotope in resin particles in methacrylate capsule [58], or a pancake with radioisotope-labelled resin [32]. Radiolabelled liquid is utilised for small intestine and colon transit to reduce delayed gastric emptying caused by solids [9]. ^{111}In-resin pellets are no longer used [59]. Cremonini et al. [59] developed and validated a process of radiolabelling activated charcoal with ^{111}In.

Two methods for delivery of the markers are in clinical use: resin-coated capsule (Mayo Clinic Rochester, MN) [60], and using a solid–liquid meal [61]. Maurer and Parkman [8] conclude that, in practice, one should image the colon at 24 and 48 h to identify patterns of transit different from normal. Liquid markers empty from the stomach faster than solid markers, while there is no difference in small bowel transit for the two markers [37].

Presentation of data and analysis

Studies use many different reporting modes including: transit time in hours (T1/2), % radioactivity retained (%RET), proximal colonic emptying (PCE) or centre of mass (Tables 6, 7). The geometric centre (GC) for radioactivity is the weighted average of radioactivity over specific regions of the bowel—effectively the median location of radioactivity. A low value implies that the radioactive material is close to the caecum, while a high value indicates that it is distal [9]. Unfortunately, groups vary on the number of regions they identify (Table 8) and this makes comparisons between groups difficult. Centre of mass data are simple but give no information if the isotope is moving as a bolus or how far it is spread [32]. Eising and von der Ohe [12] suggested measuring PCE as well as GC and found this value differentiated patients with slow colonic transit and pelvic outlet obstruction more clearly. Knowles

Table 4 Paediatric normative values for gastrointestinal transit measured using plastic markers

Author	Reference	X-ray on day	*N*	Age range	CTT (h)		
					Mean	SD or range	Upper 95th
Arhan 1981	[19]		23	2–15 years	29	4	62
Corazziari 1985	[46]		78	2 months to 12 years	25	3.7	32.4
Bautista Casasnovas 1991	[47]	4	10	10–14 years	37.8	6.2	50.2
Zaslavsky 1998	[28]	4	13	12–18 years	30.18	13.15	50.4
Gutierrez 2002	[48]	7	15 m 15 f	2–14 years	29.08	8.3	45.7
Wagener 2004	[45]	7	22	4–15 years	39.6	21.4	84
Mean					31.78		

CTT colonic transit time, *m* male, *f* female

Table 5 Paediatric studies examining effects of age, gender or constipation using plastic markers

Author	Reference	Age	Gender	Constipation		
				Yes	*N*	Age (years)
Bautista Casasnovas 1991	[47]			Y	14	
Zaslavsky 1998	[28]			Y	13	12–18
Gutierrez 2002	[48]	Y	Y	Y	38	2–14
Park 2004	[49]			Y	38	2–10
Zaslavsky 2004	[50]	Y	Y		48	12–18
Benninga 2004	[51]			Y	215	5–17

N number in study

and colleagues [62] defined two new variables: gradient of GCI progression and estimated evacuation time.

Camilleri et al. [63] concluded that quantitation of isotopic counts in colonic regions on scans taken at 4 and 24 h provides an accurate summary of colonic transit, with acceptable specificity at a high sensitivity in the detection of motility disorders of the colon. The emptying rate of the proximal colon was significantly different between healthy and constipation groups; the GC at 24 h was significantly lower in a constipation group than in the healthy controls. Using logistic discriminant analysis, simple summaries of transit also had significant discriminant value; these included the isotopic contents in the ascending, transverse and descending colon at 4 h and the counts in the ascending and transverse colon and stool at 24 h. At 90% sensitivity, the specificity of the transverse colon counts at 4 h was 79%, which is identical to the specificity of the proximal colon emptying rate, both adjusted for age.

Inter-observer variability

Individual delineation of ROI may vary [64] and although visual assessment is simple, it is unreliable with agreement in a mere 25% of studies [65, 66]. Colonic data presented as curves, parametric images or GC can also be difficult to interpret producing a fairly large variability in inter- and intra-observer reporting of gut transit in healthy adults [58, 67, 68]. Notghi et al. [69] described a simple method of reporting the summarised GC but this has not been widely accepted. Freedman et al. [66] found that the best agreement between assessors occurs when they view either parametric images or plots of arrival/clearance times in the right and left colon, with agreement in 94% of studies. These display methods may become more widely used in the future and allow easier comparisons between patients and importantly between centres.

Reproducibility

The Mayo Group has attempted to develop a reproducible technique to evaluate gastrointestinal motor function [59]. They have measured normal values and reproducibility of gastrointestinal and colonic transit of solids, in 37 healthy adults aged 18–60 years, in both genders, and compared plastic marker and scintigraphic transit. 21 subjects had a repeat scintigraphic test 3 weeks later. Intra-individual correlation between repeat studies of total colonic transit was good for normal subjects using scintigraphy [59]. Differences were within 10% for over 60% of subjects, but varied by more than 1 GC in 37% of subjects at 24 h and 26% of subjects at 48 h [59]. They found the GC at 48 h to be more reproducible than the GC at 24 h. Madsen et al. [70] reported larger variations between subjects than in repeat studies. McLean et al. [52] performed repeat studies in ten females and nine males finding a mean difference of 15–20% at 24 h in % retention of radioactivity. They concluded that intra-subject difference was greater than intra-operator analysis variability. Degen and Phillips [67] also performed repeated studies on men, showed a median difference of 0 with a wide range influenced by several outliers and concluded that reproducibility was large between repeat studies.

Table 6 Scintigraphy studies showing type of data studied and mode of presentation

Authors	Reference	Data presented as	Normal subjects		Did they study					
			N	Age (years)	Reproducibility	Age	Gender	Segmental transit	Simultaneous plastic markers	Chronic Constipation
Proano 1990	[11]	T1/2, %rad	14 (8 m)	19–39						
Stivland 1991	[58]		5					Y	Y	Y
McLean 1992	[52]	T%Ret, T1/2	41		Y, 10 f, 9 m	Y	Y			
Krevsky 1992	[61]	Time activity curves, GC	15							
Roberts 1993	[76]	GCI, activity curves	16	19–59				Y		Y
van der Sijp 1993	[32]	Centre of mass, time activity curve	12	24–55				Y	Y	Y
Degen and Phillips 1996	[67]	GC, MCTT	32	19–45	Y		Y		Y	
Eising 1998	[12]	GC, PCE	22	8–68					Y	Y
Knowles 1999	[85]	Neurological tests	20	13–62		Y			Y	Y
Scott 2001	[62]	Time activity curves, GCI gradient, evacuation times	7	22–59		Y		Y	Y	Y
Knowles 2001	[99]	Presence of smooth muscle inclusion bodies	80	20–92		Y				Y
Graff 2001	[37]	Mean transit time	16	20–30		Y	Y			
			16	38–53						
Cremonini 2002	[59]	GC	37	28–50	Y	Y	Y	Y	Y	
Lundin 2004	[64]	GC, %rad	13	38–54				Y	Y entry	Y
Park 2006	[107]	GC, colonic filling	48 (12 m)	18–65				GE and colon		
Lundin 2007	[75]	GC	11	38–54				Y	Y	Y
Zarate 2008	[101]	GC , %RET						Y	Y entry	Y
Paediatric										
Tota 1998	[81]	Transit time (h) [Italian]	15	3–14						Y
Chitakara 2004	[82]	GC 24 h								Y
Cook 2005	[84]	GC 24 h								Y
Reviews and methodological studies										
Notghi 1995	[69]	Pictorial representation, geometric mean, % activity in each region						Patterns		Y
Maurer and Krevsky 1995	[7]	Review								Y
Maurer and Parkman 2006	[8]	Update						Y	Y	Y
Freedman 2006	[66]	Data processing and presentation			Observers, methods				Y	Y

N number of subjects studied, *T1/2* 50% of transit time, *% rad* percent radioactivity in the segment, *T%Ret* total retained activity as percentage of activity at 6 h, *PCE* proximal colon emptying, *GCI* geometric centre index, *%RET* percent radioactivity retained in colon, *f* female, *m* male, *Y* yes

Normative data for adults from scintigraphy

Because of the different measurement methods, transit times measured by scintigraphy are summarised in Tables 7 and 8. A number of studies used scintigraphy on small normal populations [55, 57, 60, 71–74]. Healthy adults took 3–8 days to evacuate the tracer [32, 64, 75]. Figure 1 shows normal data from three studies that defined five ROI. The mean values are very similar. In a recent update, Maurer and Parkman [8] defined the normal (mean ± SD) GC values

Table 7 Normative data for transit measured by scintigraphy reported as %radiation or %RET

Author	Reference	Data expressed as	Age (years)	*N*	Asc colon (%)			Transverse (%)			Desc (%)			Rect/sig (%)			Stool (%)		
					12 h	24 h	48 h	12 h	24 h	48 h	12 h	24 h	48 h	12 h	24 h	48 h	12 h	24 h	48 h
Proano 1990	[11]	%rad in region	19–39 m 24–38 f	8 m 6 f	59 ± 11	22 ± 7	5 ± 2	21 ± 6	34 ± 8	30 ± 10	3 ± 1	7 ± 2	4 ± 2	2 ± 1	5 ± 3	3 ± 1	10 ± 6	32 ± 10	56 ± 11

Author	Reference	Data expressed as	Age (years)	*N*	T%Ret				Map			
					24 h	48 h	72 h	96 h	24 h	48 h	72 h	96 h
McLean 1992	[52]	T%Ret	20–80	19 m	37	9	2	0.6	85	97	98	98
			20–70	22 f	68	18	3	0.3	68	95	99	99

%rad percent radiation, *T%Ret* total retained activity as percentage of activity at 6 h, *MAP* mean activity position of isotope, *m* male, *f* female

(with seven ROI) as 4.6 ± 1.5 at 24 h, 6.1 ± 1.0 at 48 h and 6.6 ± 0.19 at 72 h based on their experience and previous studies [61].

Normal segmental transit time

Proano and colleagues [11] found most radioactivity in the ascending colon for up to 12 h, and by 24 h radioactivity was roughly equally distributed between ascending colon, transverse colon and stool. By 48 h, most radioactivity was evacuated although there was still 30% in the transverse colon with the rest of the colon devoid of counts. At 24 and 48 h, the amount of radioisotope in the descending and rectosigmoid colon was significantly lower than in the transverse colon or stool. Roberts et al. [11, 76] also found that storage seems to occur in the transverse colon while the left colon acts as a conduit. These observations support studies showing heterogeneous functions for proximal and distal colon including differences in response to stretch, electrical field stimulation, meals and pharmacological doses of cholinergic agonists and serotonin.

Colonic filling at 6 h, a surrogate for oro-caecal and small bowel transit shows marked individual variance and is considered not useful diagnostically [59, 77].

Age and gender

Several studies have evaluated the effects of ageing or gender on colonic transit (Table 6). Transit was either not influenced by age in adults aged 18–60 years [59], or slower in older women [37] or in older subjects [22, 70]. Graff et al. [37] also found that ageing produced accelerated gastric transit and small intestine transit in men and women. In some studies, no effect of gender was found [59, 70]. When a difference is reported, colonic transit rate is slower in women than men [37, 52, 67] with slower gastric emptying in women than men [67, 78]. Degen and Phillips [67] found slower colonic transit in women than in men (12 women, 20 men, aged 19–45 years), with a significant difference in GC already by 12 h.

There are variable conclusions on the effects of menstrual cycle and sex hormones, see [37], with premenopausal women showing slower emptying than postmenopausals and men of any age making separate reference values for young to middle aged women necessary [43, 79]. Others reported no consistent changes in gastric emptying or constipation during menstrual cycle [31, 67, 80].

Graff et al. examined scintigraphic transit in 32 adult subjects, 16 aged 20–30 years and 16 aged 38–51 years, with 8 males and 8 females in each age group. They found slower transit in females compared to males and in the

Table 8 Normative data for transit measured by scintigraphy and presented as GC

Author	Reference	*N*	Age (years)	No. of ROI	GC 6 h	GC 8 h	GC 24 h	GC 48 h	GC 72 h
Krevsky 1992	[61]		23–42	7			4.6 ± 1.5[a]	6.1 ± 1.0[a]	6.6 ± 0.19[a]
Roberts 1993	[76]	16	19–59	7		±0.05	1.97–6.76[b]	3.6–7.0[b]	6.26–7.0[b]
Eising 1998	[12]	22	8–68	5		1.48 ± 0.05[c]	2.83 ± 0.25[c]	4.07 ± 0.55	
Cremonini 2002	[59]	37	28–50	5			2.67 ± 1.09[a]	3.89 ± 0.15[a]	
Lundin 2004	[64]	13 (2 male)	38–54	8	2[c]		3.5[d]	5[d]	6.5[d]
Park 2006	[107]	11 placebo	18–65	5		1.4 ± 0.1[c]	2.6 ± 0.3[c]		
Centre of mass									
van der Sijp 1993	[32]	12	19–50	8				4.4 (3.0–5.5)	5.0 (3.5–6.9)
Paediatric									
Cook 2005	[84]	24	Constipation children	6	2 ± 0.5[a]		3.9 ± 1.1[a]	5.2 ± 0.9[a]	

[a] Values are mean ± SD

[b] Values are range

[c] Values are mean ± SEM

[d] Values are mean

older but not in the younger group [37]. They reported transit in hours (CTT) rather than GC. It is interesting that a birth cohort study in Rochester, MN [1, 3] found that up to 13 years old, the incidence of constipation is the same in boys and girls, and then in adolescents aged 13–16 years girls had 2.6 times the incidence of constipation and this increased to 4.2 times in girls aged 17–20 [3]. Together, these data suggest that transit is slowed in girls at puberty.

Normative data for children

There is one report of normative data in children [81] and one in adolescents [82] and both report transit time rather than GC (Table 6). Tota et al. [81] studied 15 normal children aged 3–14 years and 58 with constipation using scintigraphy. Chitkara and colleagues [82] evaluated colonic transit in 41 adolescents with refractory constipation who had undergone anorectal manometry and balloon expulsion tests. 30% had slow colonic transit alone and 12% had slow colonic transit with abnormal balloon expulsion. This study divided the large bowel into ascending, transverse and descending colon and rectosigmoid regions and used methods presented by the Mayo group [59, 63, 83]. Chitkara et al. [82] did not have a control group of adolescents but defined a GC at 24 h of less than or equal to 1.6 (using five ROI, see Fig. 1) as slow colonic transit and of greater than 3.8 as fast colonic transit.

As there are no reports of normative GC data for children measured with scintigraphy, these values have to be estimated from either paediatric values measured by plastic marker (Table 4) or adult values measured by scintigraphy (Table 8). As plastic marker studies have shown there is a similar rate of transit in children and young adults (Tables 1, 2, 4), it seems reasonable to use normative scintigraphy data from young adults to predict transit in children and adolescents.

Cook et al. [84] examined 101 children with chronic constipation. They did not have a control group but for normal they used a definition that the tracer reached the caecum by 6 h, passed through the colon, and was largely excreted by 48 h. This was based on the data for adult male % retention described by McClean et al. [52]. As expected using the adult definition, the mean GC in the paediatric group diagnosed with normal transit is similar to normal adults (Table 8; Fig. 1b).

Simultaneous comparison of radioisotope and plastic marker studies

A number of studies have performed simultaneous comparison of radioisotope and plastic markers in healthy adult subjects [32, 59, 67, 75, 85] (Table 6). Comparison is difficult due to the different dynamics of the two methods. In plastic marker studies, markers are ingested for several days and one picture is taken. In scintigraphic studies, radioactive tracer is ingested once and multiple scans are collected over several days. They also differ in the way transit time is defined and calculated resulting in variation in normative values [45].

Emptying of non-digestible plastic makers correlates with a solid scintigraphy method for gastric emptying [34, 86] and small bowel transit [87]. Measurement of oro-caecal transit using H2 breath test and plastic markers also shows significant correlation [88].

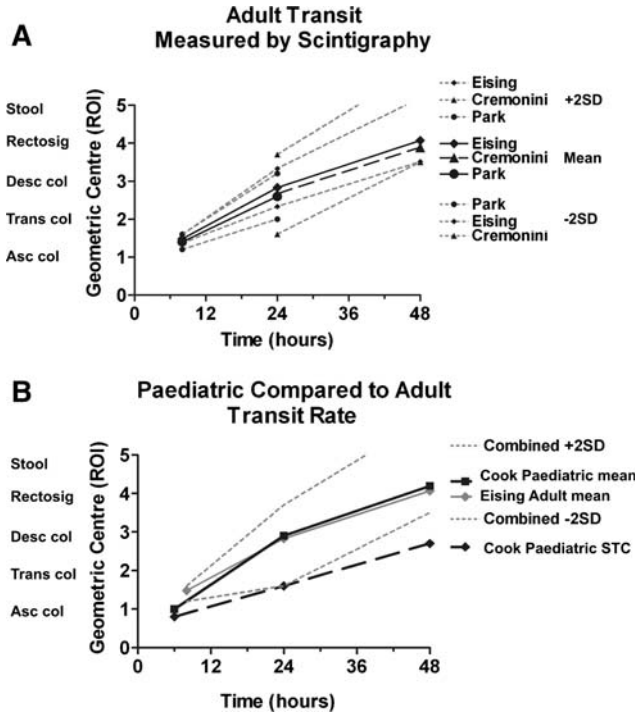

Fig. 1 Transit measured by scintigraphy. **a** Progression of geometric centre of tracer in normal adults measured in three separate studies all using the same five regions of interest (ROI, *Y* axis) to outline the bowel. The plot shows mean data and mean ± 2 SD for each study. Data from Eising et al. [12], Cremonini et al. [59] and Park et al. [107]. **b** Transit in paediatric patients compared to the adult data shown in **a**. *Dotted lines* in *grey* show the adult data of ±2 SD plotted against the left *Y* axis. Paediatric data from Cook et al. [84] show mean value for children considered to have normal transit and mean value for children diagnosed with slow transit constipation (STC). Paediatric data were collected defining the small intestine as an addition ROI number 1. Paediatric data were plotted against the right *Y* axis showing six ROI. ROI 2–6 in Cook et al. are the same as ROI 1–5 in the adult studies

These studies have shown good correlation for colonic transit [32, 58, 67, 75], but plastic marker studies show faster transit than radioisotopes [11–13, 32, 58], by 1–2 (out of 8) ROI or 2.8–18.2 h. van der Sijp et al. [32] concluded that the radioisotope technique was more reliable and should be the gold standard. This conclusion is supported by the American Motility Society Task Force on Gastrointestinal transit [9].

Repeat studies in adults show that results are reproducible for both plastic markers and scintigraphic studies of colonic transit with some outliers representing individual variability [59, 67, 75]. The magnitude of individual variability was the same with both techniques suggesting it reflects physiological variability rather than methodological factors [67]. In repeat studies, the GC at 48 h was more reproducible than the GC at 24 h. 25% of subjects had more than 1 GC difference at 24 h [59].

Issue relating to both methods

Segmental accumulation of a marker may occur within a diseased segment or may be due to more distal obstruction causing stasis [64]. In healthy adults, transit through the left colon may be rapid [11].

Comparison of plastic marker and scintigraphy studies for investigating constipation

In a direct comparison, total CTT results are similar by radio-opaque marker study and by scintigraphic study [75]. Patients with suspected colonic inertia in plastic marker studies also have delay in progression of radioisotope indicating colonic inertia [76] with 38% of radioactivity remaining in the transverse colon at 48 h compared to 5.3% in controls. A significant difference between plastic marker and scintigraphy results has been noted in the descending colon, where more patients were diagnosed with prolonged transit by scintigraphy than by plastic marker study [64, 75]. In patients who demonstrated slowing in the distal colon after 48 h, the abnormality of transit appears localised to the descending colon and rectosigmoid [76].

The upper normal limit (UNL), defined as mean ± 2 SD, is used to identify patients with transit outside the normal range. Slow colonic transit is not distinguishable from normal transit at 6 h, but from 24 h, adults with STC show slower transit, representing transit from the mid-transverse colon (Fig. 2). In practice, scintigraphic images collected at 24 and 48 h are thought to give the best index to predict delayed colonic transit [8, 59, 76, 89] and clinical trials also show significant effects of agents at 24 and 48 h

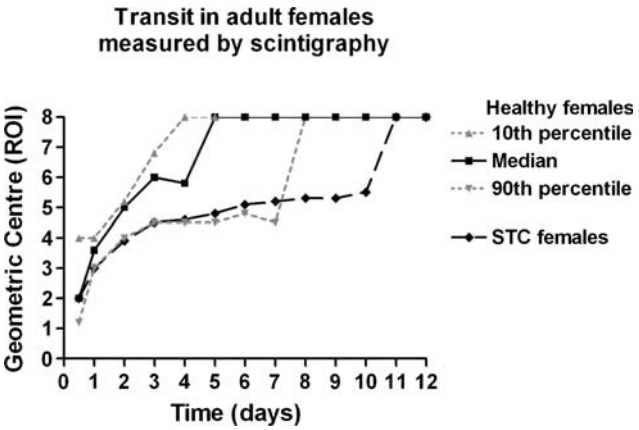

Fig. 2 Comparison of normal transit and slow transit constipation in adult females. Transit measured by scintigraphy. Progression of geometric centre of tracer for 11 normal female adults showing median, 10th and 90th percentiles and for 31 female adults with slow transit constipation (STC) showing median value. Data from Lundin et al. [75]. The STC values are significantly different to normal from 24 h onwards

[90–92]. In adults, using seven ROI, the diagnosis of colonic inertia is made when the GC is <4.1 at 48 h [8, 9, 63], with an image at 72 h to include/exclude functional outlet obstruction. Repeat tests may also be more reproducible at 48 than 24 h [59].

Three transit patterns have been described in adults with chronic constipation: normal transit, colonic inertia and rectosigmoid obstruction [7]. Three patterns of slow colonic transit have also been described: generalised slow transit with diffuse retention throughout the colon; right-sided retention proximal to the splenic flexure (colonic inertia), and retention in the rectosigmoid (functional rectosigmoid obstruction or functional outlet obstruction) [8, 9, 56]. Studies vary in the proportions of patients with normal, slow colonic transit or anorectal defects (Table 9) probably depending on the referring population. Some studies record predominantly distal obstruction [49, 93–96], while others record predominantly slow colonic transit [12, 23, 84, 97–99]. In children and in adolescents, slow transit in the proximal colon occurs in 13–50% and anal retention in 22–55%, with some children having both (Table 9) [48, 50, 81, 82, 84]. In over 2,000 adult patients with intractable constipation investigated by transit studies, half had delayed colonic transit [100]. Many patients with pelvic floor dysfunction also have slow colonic transit [96] (Table 9), so rectal measures alone cannot predict motility in the proximal colon and vice versa [101].

Colonic and rectal symptoms cannot discriminate amongst the physiological subgroups of patients with

Table 9 Subtypes of constipation in different studies

Authors	Reference	Subjects	Plastic or scintigraphy	Transit type								
				Slow proximal transit	%	Visible at (h)	Normal transit	%	Anal Ret	%	Anal Ret with SCT	%
Tota 1998	[81]	58 children	SC	13/58 R, 19/58 L	22, 33		6/58	10	20/58	34		
Gutierrez 2002	[48]	38 children	PI	5/38	13		19/38	50	14/38	37		
Cook 2005	[84]	101 children FC not FFR	SC	50/101	50		24/101	24	22/		101	22
Benninga 2004	[51]	135 paediatric const	PI		44			56		55		
		56 paediatric functional faecal soiling						91		48		
Zaslavsky 2004	[50]	48 adolescents FC	PI	29/48	60		8/48	17	6/48	13	5/48	10
Chitkara 2004	[82]	67 adolescents	SC	12/41	30			20	28/67	42	5/41	13
Roberts 1993	[76]	37 adults	SC	26/37	70	48	5/37	14	6/37	16		
Grotz 1994	[33]	184 adults	PI	70/184	38		60/184	33	30/		184	16
24/184	13											
Surrenti 1995	[96]	70 adults			27				50%			
Eising and von der Ohe 1998	[12]	32 adults idiopathic const	SC	26/32	81				6/32	19		
Knowles 2003	[100]	2,004 adults	SC		54 f, 31 m							
Lundin 2007	[75]	31 adults	SC	24/31	77	24	1/31		17/31	55		
Sadik 2008	[10]	243 adults	PI		34		37%					
Zarate 2008	[101]	196 const adults	PI then SC	41/196	21		28/196	14			29/196	15
Park 2004	[49]	38 cerebral palsy children	PI	9/10 const	90				1/10	10		
				17/28 non-const	61				12/18	67		
Freedman 2006	[66]	Spinal injury	SC	6/96	37	24			5/16	31		

Anal Ret anal retention, *SCT* slow colonic transit, *SC* scintigraphy study, *PI* plastic marker study, *R* right-sided delay, *L* left-sided delay, *FC* functional constipation, *FFR* functional faecal retention, *const* constipation

severe intractable constipation [33]. There are no reports on how much studies repeated on patients with slow colonic transit vary over time.

Use of transit studies to direct therapy

It has been suggested that patients with different subgroups of constipation might benefit from different treatment strategies [8, 12, 28, 45, 81, 102]. The prokinetic [60, 103–107] or constipating effect [61] of drugs can be demonstrated using scintigraphy. Decisions about surgery can be based on assessing upper GI motility in addition to colonic transit [108]. Positions for stomas may be determined by the site of delay [16]. The presence of abnormal gastric emptying, small bowel transit and colonic transit suggests diagnosis of chronic idiopathic intestinal pseudo-obstruction [8]. In addition to demonstrating slow colonic transit, these tests may be used to determine if constipation is caused by too little movement (colonic inertia) or too much uncoordinated movement [9, 109]. Patients who might benefit from colectomy may be selected on the basis of small and large bowel transit studies [110]. A minimum study size of 14 is necessary to see any statistically significant differences in transit following interventions [37].

Conclusion

Plastic marker studies are simple and can clearly measure prolonged transit, but segmental transit is unreliable unless methods to outline the bowel are used. Radioisotope studies require a specialist centre and several days to perform but give detailed information on transit through the stomach, small and large bowel. Plastic marker studies and scintigraphy give similar results in the ascending and transverse colon but total transit times with plastic markers are always faster. Normal transit is affected by age and gender and is slower in older women than men. Normative data are available for adults and children using plastic markers but only for adults using scintigraphy. However, as plastic marker studies show similar transit rates in children to young adults, it is reasonable to use young adult or adult male normative values for studies of paediatric transit. Separation of slow transit from normal transit in the ascending colon is apparent at 24 and 48 h. Determination of transit through the distal colon/rectum may require studies of more than 7 days. Standardization of the number of ROI and methods of reporting are still needed for scintigraphy. Scintigraphic studies are diagnostically useful to guide treatment, with good quantitation and reliability for children.

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