

Outcome measures used to assess gastrointestinal tract involvement in adults and children with systemic sclerosis: a scoping review

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Supplementary Table S1. Excluded GI measures

GI Region/Domain	Outcome measure	Rationale for exclusion
Oropharyngeal	Maximal mouth opening	Oral opening considered a manifestation of cutaneous disease, covered in separate review
	Mouth Handicap in Systemic Sclerosis Score (MHISS)	Oral opening considered a manifestation of cutaneous disease, covered in separate review
Oesophageal	Oesophageal ultrasound	Research outcome, not in widespread clinical use
Gastric	Cutaneous Electrogastrography (EGG)	Research outcome, not in widespread clinical use
Small Intestinal	Doppler ultrasound of superior mesenteric artery	Not considered clinically relevant for SSc
	Cellobiose/Mannitol (Ce/Ma) test for intestinal permeability	Research outcome
	Fructose Breath Test	Glucose and Lactulose breath tests are more widely used and clinically available to diagnose SIBO, both of which are included in this review.
	Lactose Breath Test	Glucose and Lactulose breath tests are more widely used and clinically available to diagnose SIBO, both of which are included in this review
Colorectal	Endoanal ultrasound (EUS)	Research outcome, not in widespread clinical use
	Endoanal MRI	Research outcome, not in widespread clinical use
	3D high resolutions anorectal manometry (3DHRAM)	Not widely clinically available, particularly in paediatrics; Standard anorectal manometry included in this review
	Barium Enema	Not considered clinically relevant for SSc
Nutritional	Bioelectrical Impedance Analysis (BIA)	Primarily a research outcome in paediatrics
Patient-Reported Outcomes (PROs)	Global symptomatic score (GSS), NIH PROMIS GI symptom scales, Gastrointestinal Symptoms Severity Index (GISSI), Bristol Stool Scale, Jorge-Wexner Score (incontinence), Fecal Incontinence Quality of Life Scale (FIQOL), Rome 4 criteria (constipation), Cleveland Clinic	Not SSc-specific; UCLA GIT 2.0 included which covers many of these symptoms and is much more widely used/studied in SSc

	Fecal Incontinence Severity Scoring (CCIS), Modified Miller Score (incontinence score), MD Anderson Dysphagia Inventory Scale (MDADI), Short Form 36, Frequency Scale For Symptoms of GERD (FSSG), GERD questionnaire (GERD-Q), Composite Autonomic Symptoms Score-31 (COMPASS-31), Intestinal Visual Analogue Scale, Quality of Life in Reflux and Dyspepsia questionnaire (QOLRAD)	
	Scleroderma Health Assessment Questionnaire (S-HAQ), Global symptomatic score (GSS), Medsger Severity Scale (GI tract is a component), Short Form 36 (SF-36)	Not GI-specific (covered in separate quality of life review)
Other	PDG-PET-MRI	Research outcome for GI tract, not considered clinically relevant for GI disease in SSc
	Whole Gut Scintigraphy	Included scintigraphy data for individual GI segments when reported, rather than whole gut transit time

Supplementary Table S3. Studies with identified cohort overlap

Johns Hopkins Scleroderma Center (Baltimore, USA)			
Study ID	Year	N	GI outcome measures extracted
McMahan 2022	2022	71	<i>oesophageal scintigraphy, gastric scintigraphy, colonic scintigraphy, GIT 2.0</i>
Tucker 2023	2023	95	oesophageal manometry
Cheah 2023	2023	100	<i>colonic scintigraphy, GIT 2.0</i>
Adler 2022	2022	97	<i>oesophageal scintigraphy, gastric scintigraphy, colonic scintigraphy, GIT 2.0</i>
Dein 2021	2021	31	anorectal manometry, <i>colonic scintigraphy, GIT 2.0</i>
DiRenzo 2021	2021	46	<i>oesophageal scintigraphy, gastric scintigraphy, colonic scintigraphy, GIT 2.0</i>
CONQUER Registry (Multicenter, USA)			
Study ID	Year	N	GI outcome measures extracted
Luebker	2023	415	<i>GIT 2.0</i>
Luebker	2023	211	<i>GIT 2.0</i>
SCTC UCLA GIT 2.0 Development/Validation Cohorts			
Study ID	Year	N	GI outcome measures
Khanna 2009	2009	152	<i>GIT 2.0</i>
Khanna 2011	2011	152	<i>GIT 2.0</i>
Bae 2013	2013	55	Oesophageal manometry, endoscopy, upper GI with small bowel follow through, gastric scintigraphy, lactulose breath test
Nagaraja 2014	2014	167	<i>GIT 2.0</i>
SCTC UCLA GIT 2.0 Longitudinal Cohort			
Study ID	Year	N	GI outcome measures
McMahan 2019	2019	116	<i>GIT 2.0</i>
Suliman 2021	2021	115	<i>GIT 2.0</i>

University of Utah (Salt Lake City, USA)			
Study ID	Year	N	GI outcome measures
Frech 2011	2011	10	<i>GIT 2.0</i>
Murtaugh 2013	2013	24	<i>GIT 2.0, MUST</i>
Rouen University Hospital (Rouen, France)			
Study ID	Year	N	GI outcome measures
Marie 1998	1998	17	<i>oesophageal manometry, antroduodenal manometry</i>
Marie 2001	2001	22	<i>gastric scintigraphy, endoscopy</i>
Marie 2006	2006	133	<i>oesophageal manometry, endoscopy</i>
Marie 2009	2009	51	<i>glucose breath test</i>
Marie 2012	2012	57	<i>¹³C-octanoic acid breath test</i>
Marie 2015	2015	80	<i>oesophageal manometry, ¹³C-octanoic acid breath test</i>
Marie 2016	2016	99	<i>Esophageal Manometry, ¹³C-octanoic acid breath test, glucose breath test, antroduodenal manometry</i>
Genoa/IRCCS San Martino (Genova, Italy)			
Study ID	Year	N	GI outcome measures
Savarino 2009	2009	40	<i>Oesophageal manometry, pH probe</i>
Savarino 2013	2013	99	<i>Oesophageal manometry, lactulose breath test, ¹³C-octanoic acid breath test</i>
Gemignani 2013	2013	50	<i>Oesophageal manometry, lactulose breath test, glucose breath test, ¹³C-octanoic acid breath test</i>
Zentilin 2018	2018	25	<i>Oesophageal manometry, pH probe, BMI</i>
Canavesio 2023	2023	42	<i>Oesophageal manometry</i>
Mayo Clinic Arizona (Scottsdale, USA)			
Study ID	Year	N	GI outcome measures
Umar 2016	2016	160	<i>Oesophageal manometry, GIT 2.0, anorectal manometry, BMI</i>
Crowell 2017	2017	200	<i>Oesophageal manometry</i>
Bering 2021	2021	100	<i>GIT 2.0</i>
Northwestern University (Chicago, USA)			
Study ID	Year	N	GI outcome measures

Carlson 2016	2016	111	<i>Oesophageal manometry</i>
Stern 2018	2018	38	<i>Oesophageal manometry, pH probe, endoscopy</i>
Showalter 2021	2021	138	HRCT
Carlson 2022	2022	32	FLIP, <i>Oesophageal manometry</i>
Regensburg University (Regensburg, Germany)			
Study ID	Year	N	GI outcome measures
Lock 1996	1996	20	<i>Oesophageal manometry</i>
Lock 1997a	1997	50	<i>Oesophageal manometry</i>
Lock 1997b	1997	26	<i>Oesophageal manometry, Anorectal manometry</i>
Lock 1998	1998	43	<i>Oesophageal manometry</i>
Lund University (Lund, Sweden)			
Study ID	Year	N	GI outcome measures
Bartosik 2014	2014	19	Anorectal manometry
Andreasson 2016	2016	98	MUST, Oesophagram
Royal Free Hospital (London, UK)			
Study ID	Year	N	GI outcome measures
Pakozdi 2009	2009	18	Oesophageal scintigraphy
Thoua 2011	2011	44	Anorectal manometry
Raja 2016	2016	18	GIT 2.0
Aarhus University Hospital (Aarhus, Denmark)			
Study ID	Year	N	GI outcome measures
Fynne 2011	2011	20	<i>Anorectal manometry, sitz marker study</i>
Fynne 2013	2013	14	<i>Anorectal manometry, FLIP</i>
Fynne 2017	2017	12	<i>FLIP</i>
Athens/Laikon Hospital (Athens, Greece)			
Study ID	Year	N	GI outcome measures
Karamanolis 2015	2015	30	<i>Oesophageal manometry</i>
Karamanolis 2017	2017	54	<i>Oesophageal manometry</i>

Australian Scleroderma Cohort Study (ASCS)			
Study ID	Year	N	GI outcome measures
Ross 2023	2023	143	<i>GIT 2.0</i>
Quinlivan 2024	2024	907	<i>GIT 2.0</i>
Zurich University Hospital (Zurich, Switzerland)			
Study ID	Year	N	GI outcome measures
Bütikofer 2019	2019	68	Oesophageal manometry, <i>GIT 2.0</i> , <i>endoscopy</i>
Zampatti 2021	2021	346	<i>GIT 2.0</i> , <i>Endoscopy</i>
Stamm 2024	2024	209	<i>GIT 2.0</i>
Taichung Veterans General Hospital (Taichung, Taiwan)			
Study ID	Year	N	GI outcome measures
Wang 2002a	2002	16	Colonic scintigraphy
Wang 2002b	2002	12	<i>oesophageal scintigraphy</i>
Wang 2002c	2002	32	<i>oesophageal scintigraphy</i>
Sapienza University Rome (Rome, Italy)			
Study ID	Year	N	GI outcome measures
Rosato 2021	2021	102	<i>MUST</i> , <i>BMI</i>
Rosato 2022	2022	69	<i>GIT</i> , <i>MUST</i> , <i>BMI</i>
Postgraduate Institute of Medical Education and Research (PGIMER) (Chandigarh, India)			
Study ID	Year	N	GI outcome measures
Adarsh 2018	2018	50	<i>endoscopy</i> , <i>oesophageal manometry</i> , lactulose breath test, glucose breath test, gastric scintigraphy
Adarsh 2019	2019	23	<i>oesophageal manometry</i> , <i>endoscopy</i>
Gunma University (Gunma, Japan)			
Study ID	Year	N	GI outcome measures
Kuribayashi 2019	2019	109	<i>Endoscopy</i> , <i>Oesophageal manometry</i>
Kuribayashi 2024	2024	188	<i>Endoscopy</i> , <i>Oesophageal manometry</i>

Khon Kaen University (Khon Kaen, Thailand)			
Study ID	Year	N	GI outcome measures
Chunlertrith 2014	2014	75	Endoscopy, pH probe
Sawadpanich 2019	2019	89	Glucose breath test
Marseille/Aix-Marseille University (Marseille, France)			
Study ID	Year	N	GI outcome measures
Luciano 2016	2016	44	<i>Oesophageal manometry</i> , anorectal manometry
Vitton 2021	2021	53	<i>Oesophageal manometry</i> , endoscopy
Kanazawa/Gunma Nuclear Medicine Group (Japan)			
Study ID	Year	N	GI outcome measures
Kinuya 2001	2001	47	<i>oesophageal scintigraphy</i>
Nakajima 2004	2004	35	<i>oesophageal scintigraphy</i>
Nakajima 2009	2009	32	<i>oesophageal scintigraphy</i> , gastric scintigraphy, endoscopy

Supplementary Table S4. Comprehensive overview of GI outcome measures used in SSc, including paediatric feasibility.

Region Assessed	Measure	Assessed symptom/ pathology	Tools needed	Advantages	Disadvantages	Feasibility in children Standardised/ validated
Oropharyngeal	Clinical Bedside Swallow Evaluation	Swallowing function and risk of aspiration Symptoms: Feeding difficulties, dysphagia, aspiration	Trained Therapist (Speech Language Pathologist or Occupational therapist) Office-based	No anesthesia Non-invasive No-radiation Non-instrumental clinical observation and examination for signs and symptoms of dysphagia and aspiration.	Subjective and based on the skillset of the trained therapist administering the test No standardised definitions or severity levels	Widely used Very feasible in children of all age groups
Oropharyngeal	Video fluoroscopic swallowing exam (VFSS) (Modified barium swallow study - MBSS)	Swallowing function and risk of aspiration Symptoms: Feeding difficulties, dysphagia, aspiration	Fluoroscopy (radiology suite) Speech Language Pathologist +/- Radiologist +/- Radiology technician	No anesthesia Non-invasive Instrumental clinical observation and examination for signs and symptoms of dysphagia and aspiration Can be followed over time to demonstrate change to intervention	Observational analysis (specific descriptors) by Speech Language Pathologist Operator dependent - variability in interpretation since no validated measures in children Radiation exposure Radiology suite	Very feasible in children of all age groups
Oropharyngeal	Fiberoptic Evaluation of Swallowing (FEES)	Swallowing function and risk of aspiration Symptoms: Feeding difficulties, dysphagia, aspiration	Endoscope (patient is awake) Speech Language Pathologist Otolaryngologist	No anesthesia Observational analysis by Speech Language Pathologist or Otolaryngologist Office-based No radiation	Instrumental Observational analysis Operator dependent – variability in interpretation Limited availability	Very feasible in children of all age groups
Oesophagus Stomach Small Bowel	Oesophagogastroduodenoscopy (EGD)	Assess anatomy (strictures, stenosis, hiatal hernia, etc.) and mucosa (infection, inflammation, allergy)	Endoscopy Suite Endoscope (general anesthesia) Anesthesia Gastroenterologist	Published paediatric standards regarding indications, performance, and reporting of endoscopy findings. Anatomical and mucosal information with	General Anesthesia Instrumental	Feasible in children of all age groups. Widely used modality in children to diagnose mucosal disease

		Symptoms: dysphagia, regurgitation, reflux, feeding difficulties, abdominal pain nausea/vomiting, weight loss, unexplained anaemia		corresponding pathological diagnosis		(oesophagitis, gastritis, duodenitis, etc.) and do therapeutic interventions.
Oesophagus	Fluoroscopic Oesophagram	Assess anatomy Structural assessment of oesophagus (dilation, hiatal hernia, strictures, perforation) Assess oesophageal peristalsis, bolus clearance Symptoms: feeding difficulties, dysphagia, reflux, regurgitation, vomiting	Radiology suite (Fluoroscopy) Radiologist	No anesthesia Non-instrumental Non-invasive Observational radiographic analysis by Radiologist performing the study	Radiation Exposure	Very feasible in children of all ages
Oesophagus	Oesophageal Transit Scintigraphy	Assess oesophageal function - bolus transit through the oesophagus - regional and total oesophageal transit time - total oesophageal emptying Symptoms: feeding difficulties, dysphagia, reflux, regurgitation, vomiting	Radiology suite (Nuclear medicine) Radiologist	No anesthesia Non-instrumental Non-invasive	Heterogenous protocols No validated measures in children Lack of normative paediatric data Limited availability (center dependent)	Feasible but limited due to lack of validated/standar dised measures and availability
Oesophagus	High Resolution Oesophageal Manometry	Assess oesophageal function - evaluate for oesophageal motor disorder (i.e. oesophageal dysmotility)	Endoscopy suite Oesophageal Manometry catheter GI Technician	Awake +/- sedation or anesthesia at time of EGD Standard for diagnosis of oesophageal motor disorders	Instrumental Limited to centers with capability to perform oesophageal manometry Chicago Classification has been widely used in paediatrics. Interpretation	Feasible in children; may be challenging in younger or more anxious children

		Feeding difficulties, Dysphagia, chest pain, intractable regurgitation, vomiting,	Gastroenterologist	Metrics defined by the Chicago Classification used and validated in adults and widely adopted in children.	needs to be with caution as values may differ based on age and size of patient and type of catheter and machine.	
Oesophagus	pH Impedance	Assess for Gastroesophageal Reflux (GER) – evidence of pathological reflux Symptoms: feeding difficulties, reflux, coughing, dysphagia, vomiting, regurgitation	Endoscopy suite pH-Impedance catheter GI Technician Gastroenterologist	Awake +/- sedation or anesthesia and at time of EGD Assess type of acid reflux and extent of proximal oesophageal involvement. Symptom correlation with reflux events. Efficacy of the antacid therapy.	Instrumental Requires catheter to stay for 24- hour ambulatory measurement. Risk of catheter displacement from irritation or sensitive gag reflex. Symptom correlation may be limited by parental report and child age.	Feasible in children. May not be tolerated by some children who are anxious or sensitive to intra-nasal catheter
Oesophagus	pH - probe	Assess for Gastroesophageal Reflux (GER) – evidence of pathological reflux Symptoms: feeding difficulties, reflux, coughing, dysphagia, vomiting, regurgitation	Endoscopy suite pH-catheter GI Technician Gastroenterologist	Awake +/- sedation/anesthesia and at time of EGD To assess severity of acid reflux. Symptom correlation with reflux events.	Instrumental Requires catheter to stay for 24-hour ambulatory measurement. Risk of catheter displacement from irritation or sensitive gag reflex. Symptom correlation may be limited by parental report and child age.	Feasible in children. May not be tolerated by some children who are anxious or sensitive to intra-nasal catheter.
Oesophagus	High Resolution Chest Computed Tomography (HRCT)	Assess for oesophageal diameter	Radiology suite CT scanner Radiologist	No anesthesia Non-instrumental Non-invasive Evaluate oesophageal diameter	Radiation exposure Lack of standardised protocol, validated measures, and normative values in children.	Feasible Can be used as an adjunct when HRCT is used for pulmonary monitoring.
Oesophagus	Functional Lumen Imaging Probe (FLIP)	Assess oesophageal function - Oesophageal contractility and distensibility, oesophagogastric junction opening dynamics Symptoms: feeding difficulties, reflux, coughing, dysphagia,	Endoscopy EndoFLIP catheter Gastroenterologist	Performed at time of EGD (one anesthesia) Evaluate oesophageal contractility and distensibility during endoscopy	General Anesthesia Instrumental Lack of standardised protocol and normative values in children	Feasible in children

		vomiting, regurgitation				
Oesophagus Stomach Small Bowel	UGI with SBFT	Assess structural anatomy of oesophagus, stomach, and small bowel Small bowel transit time Symptoms: vomiting, abdominal pain/distention, regurgitation, early satiety, weight loss	Radiology suite (Fluoroscopy) Radiologist	No anesthesia Non-instrumental Non-invasive Observational radiographic analysis by Radiologist performing the study	Radiation exposure Can take longer if evaluating small bowel anatomy and transit	Feasible and well tolerated in children
Stomach	¹³Cspirulina, ¹³Coctanoic Acid, ¹³C-acetate	Assess gastric emptying Symptoms: feeding difficulties, vomiting, abdominal pain/distention, regurgitation, early satiety, weight loss	Office-based Patient consumes solid (octanoic acid, spirulina) or liquid (acetate) tracer mixed in food and then breath samples are taken at specific intervals where the amount of tracer excreted is measured	No anesthesia Non-instrumental Non-invasive Spirulina is FDA approved for adults and children with normative paediatric data in children 7-18 years of age. Evaluates gastric emptying	Confounded by lung disease Limited availability (center dependent)	Feasible in children
Stomach	Gastric Emptying Study	Assess gastric emptying Symptoms: feeding difficulties, abdominal pain/distention, vomiting, regurgitation, early satiety, weight loss	Nuclear Medicine	No anesthesia Non-instrumental Non-invasive Evaluates gastric emptying	Heterogenous protocols Radiation exposure	Feasible in children
Small Bowel	Glucose Breath Test	Evaluates for Small intestinal bacterial overgrowth (SIBO) Symptoms: Abdominal pain, distention, nausea, vomiting, weight loss, diarrhoea	Office based	No anesthesia Non-instrumental Non-invasive Higher sensitivity and specificity than Lactulose breath test	Confounded by lung disease, compliance to protocol prior to test, gastroparesis and delayed OCTT (false negative result) and rapid OCTT (false positive result) Decreased accuracy compared to endoscopic	Feasible in children

					jejunal aspirate and culture (gold standard)	
Small Bowel	Lactulose Breath Test	Evaluates for Small Intestinal Bacterial Overgrowth (SIBO) Assess Oro-cecal transit time (OCTT) Symptoms: Abdominal pain, distention, nausea, vomiting, weight loss, diarrhoea	Office based	No anesthesia Non-instrumental Non-invasive	Confounded by lung disease, compliance to protocol prior to test, gastroparesis and delayed OCTT (false negative result) and rapid OCTT (false positive result) For diagnosis of SIBO decreased accuracy compared to endoscopic jejunal aspirate and culture (gold standard) Cannot isolate segmental differences in whole gut transit	Feasible in children
Small Bowel	Hydrogen Breath Test	Evaluates for Small Intestinal Bacterial Overgrowth (SIBO) (glucose breath test) Assess for carbohydrate malabsorption (lactose, fructose, sucrose) Symptoms: Abdominal pain, distention, nausea, vomiting, weight loss, diarrhoea	Office based	No anesthesia Non-instrumental Non-invasive	Confounded by lung disease, compliance to protocol prior to test, gastroparesis and delayed OCTT (false negative result) and rapid OCTT (false positive result) For diagnosis of SIBO decreased accuracy compared to endoscopic jejunal aspirate and culture (gold standard)	Feasible in children
Anorectum	Anorectal Manometry	Evaluates anorectal function Symptoms; Constipation, feeling of incomplete evacuation, fecal incontinence, difficulty with defecation, concern for pelvic floor dysfunction	Endoscopy Lab Gastroenterologist GI technician/RN	Awake +/- sedation Non-invasive No radiation Evaluates involuntary properties (intra-anal pressures, recto-anal inhibitory reflex) and voluntary properties (sensation, push effort, squeeze) of the anorectum.	Instrumental Limited to centers with capability to perform anorectal manometry Results dependent on patient cooperation. Operator dependent	Feasible and validated in children
Colon	Colonic Scintigraphy	Evaluates total and segmental colonic transit Symptoms: Constipation, feeling of incomplete	Radiology suite Radiologist	No anesthesia Non-instrumental Non-invasive	Heterogenous protocols Lack of normative values and validated measures in children Limited availability (center dependent) Radiation exposure	Feasible but limited due to limited availability and lack of standardised protocols and normative values

		emptying, fecal incontinence, difficulty with defecation				
Colon	Radiopaque marker study (ROM)	Evaluates total and segmental colonic transit Symptoms: Constipation, feeling of incomplete emptying, fecal incontinence, difficulty with defecation	Office based Radiology Gastroenterologist	No anesthesia Non-instrumental Non-invasive Very limited radiation exposure - depending on protocol may require 1 or 2 abdominal x-rays	Lack of standardised protocol and normative values in children	Very feasible in children

OCTT: oro-cecal transit time; UGI with SBFT: Upper GI with small bowel follow through