IMAGING MODALITIES IN EPI

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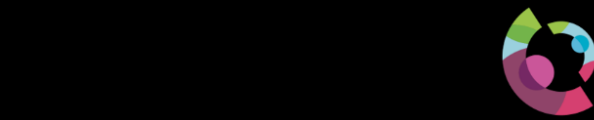
Cincinnati Children's™
changing the outcome together

Disclosures

No relevant disclosures



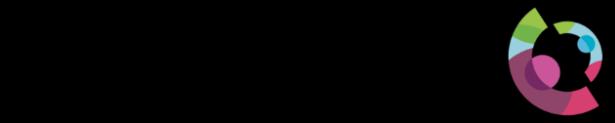
Imaging has potential to be a non-invasive measure / correlate of pancreatic exocrine function

There is A LOT of work that needs to be done to identify and validate imaging measures

Objectives

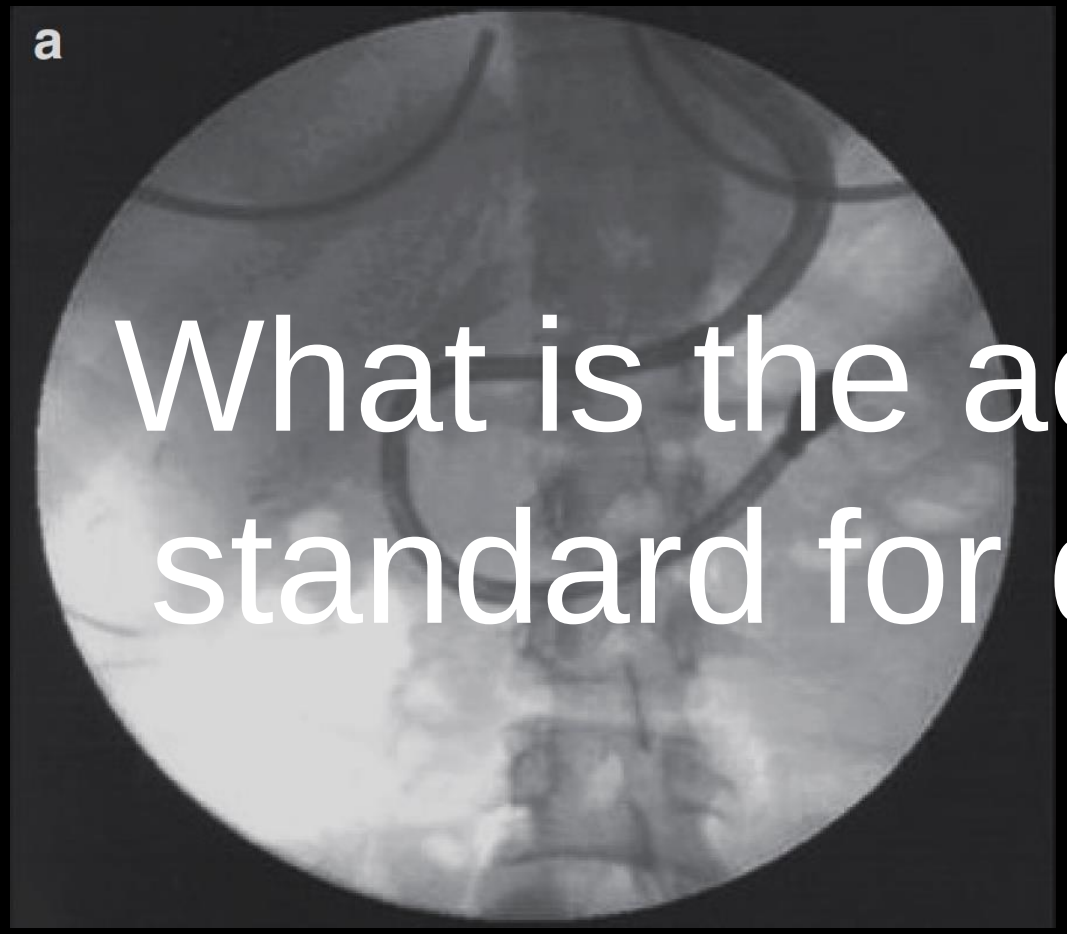
- Discuss imaging modalities relevant to the diagnosis (+/- staging) of EPI

- Provoke discussion / debate / argument around non-invasive (& invasive) assessment of EPI



Caveat

There are techniques (e.g. elastography, ASL) that I am not going to talk about because there are no data (yet) linking to exocrine function



What is the accepted reference standard for diagnosis of EPI?

Relevant Imaging Modalities

- Transabdominal US
- CT
- MRI
- Nuclear medicine

- Endoscopic US

Relevant Imaging Modalities

- Transabdominal US
- CT
- MRI
- Nuclear medicine

- Endoscopic US

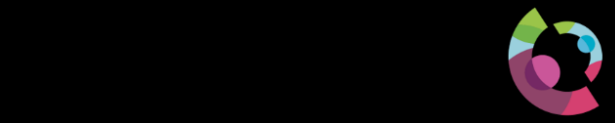
- Parenchymal volume
- Parenchymal quality
- Duct quality
- Secretory response

Mixed / Confounded Measures

- Acinar cell loss
- Beta cell loss
- Fibrosis
- Steatosis
- Perfusion

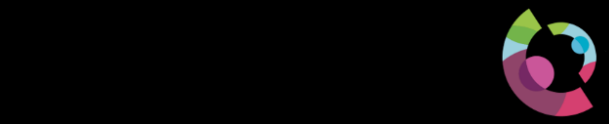
- Acinar cell loss/dysfunction
- Duct patency
- Bicarbonate
- Enzymes

- Parenchymal volume
- Parenchymal quality
- Duct quality
- Secretory response



Other Issues

- Reference standard
- Confounding
- Inter / intra-observer variability
- Technical / machine variability



Relevant Imaging Modalities

- Transabdominal US
- CT
- MRI
- Nuclear medicine

- Endoscopic US

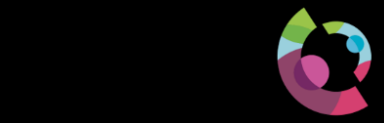
- Parenchymal volume
- Parenchymal quality
- Duct quality
- Secretory response

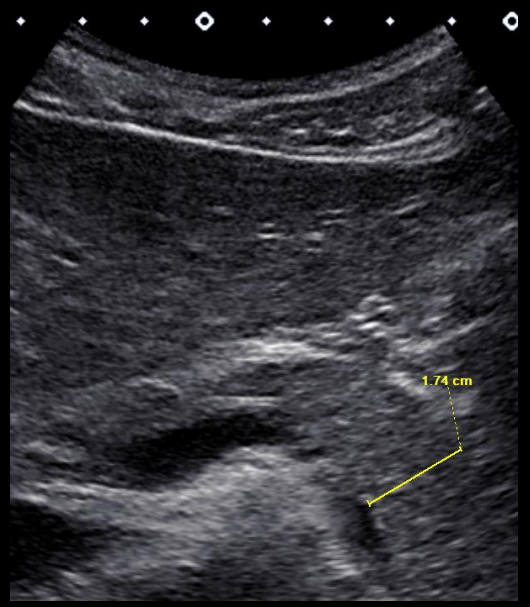
Parenchymal Volume

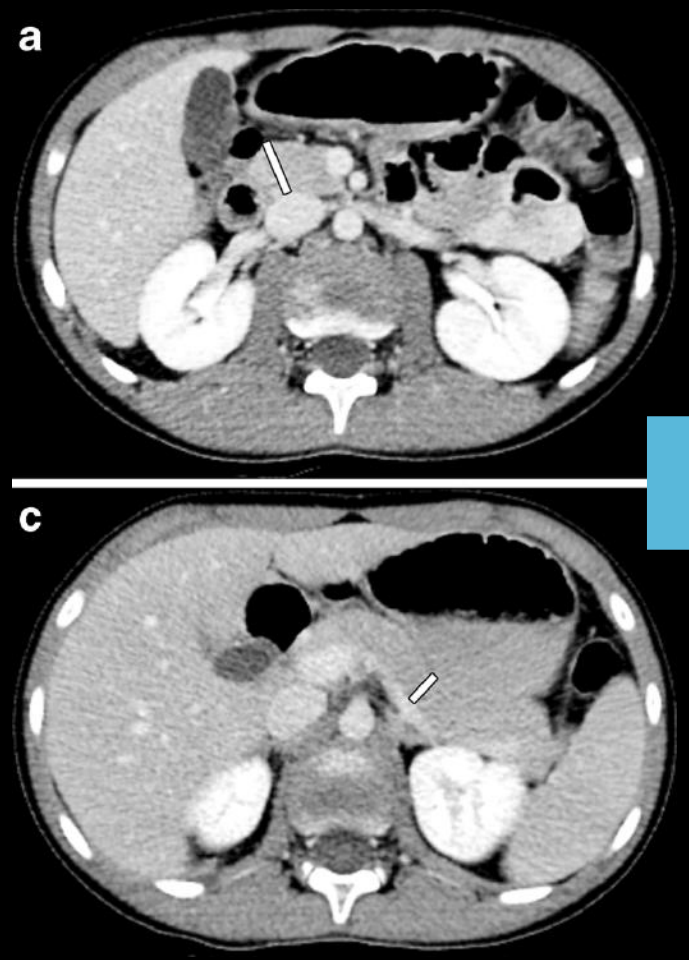
~~Linear Thickness~~

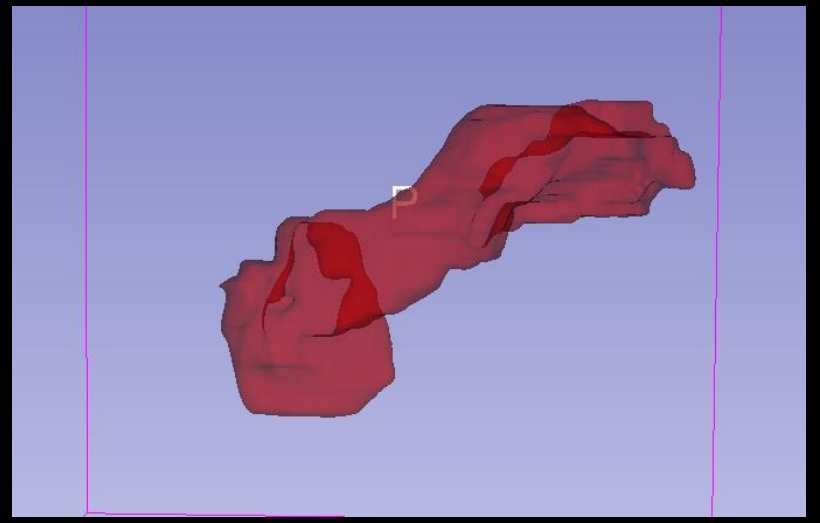
- CT
- MRI
- ? 3D US ?

Need no gap imaging



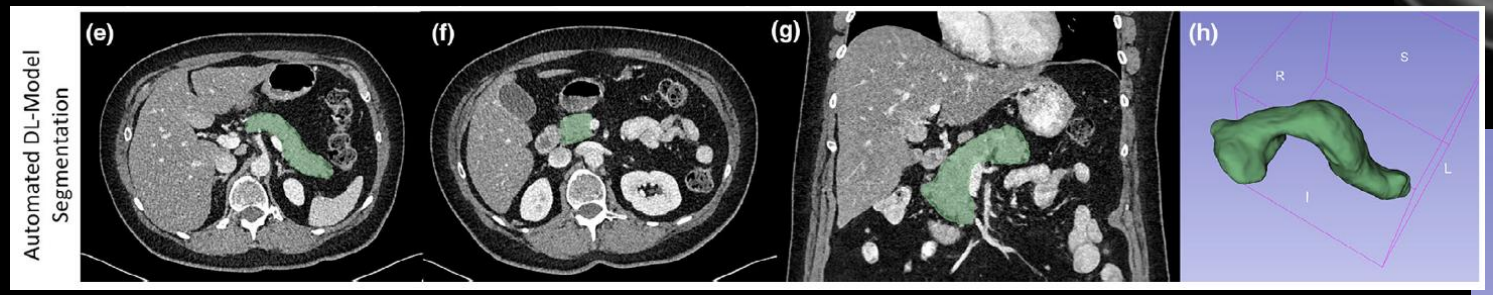

1.74 cm

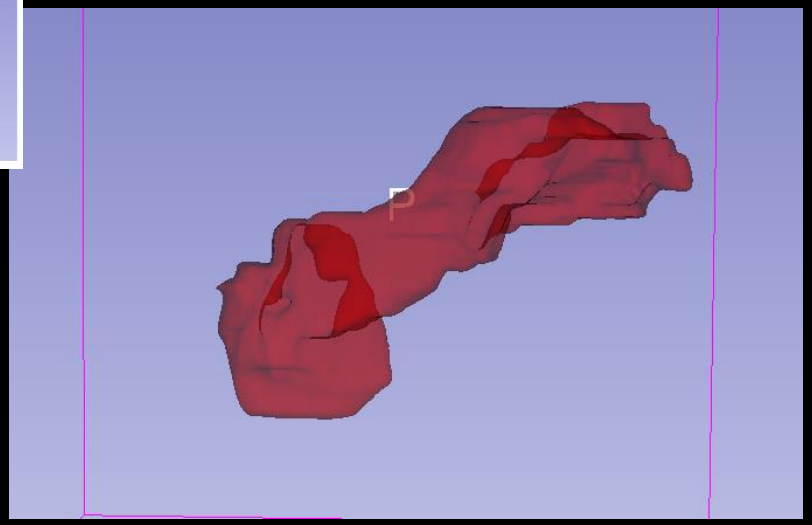

a
c



Two-stage deep learning model for fully automated pancreas segmentation on computed tomography: Comparison with intra-reader and inter-reader reliability at full and reduced radiation dose on an external dataset

Ananya Panda, Panagiotis Korfiatis and Garima Suman
Department of Radiology, Mayo Clinic, 200 First Street SW, Rochester, MN 55905, USA





Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

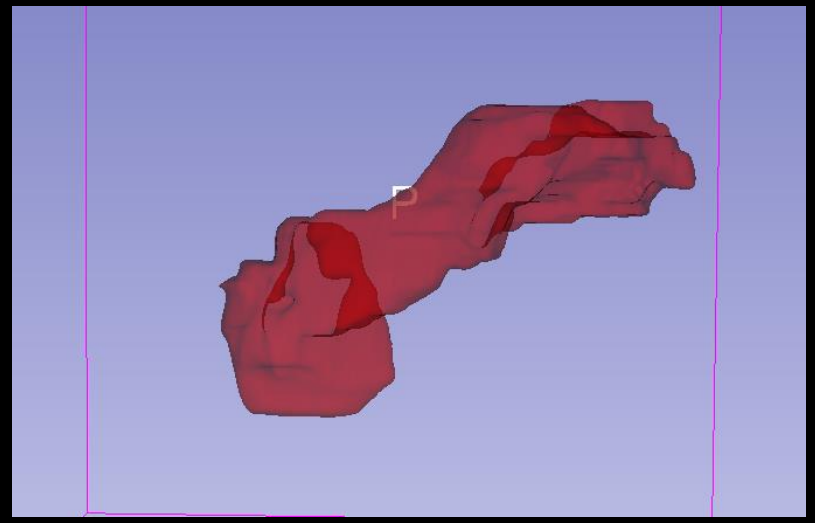
Automated pancreas segmentation from computed tomography and magnetic resonance images: A systematic review

Haribalan Kumar[a], Steve V. DeSouza[b], Maxim S. Petrov[b,*]

[a] Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand
[b] School of Medicine, University of Auckland, Auckland, New Zealand

Computer Methods and Programs in Biomedicine 178 (2019) 319–328

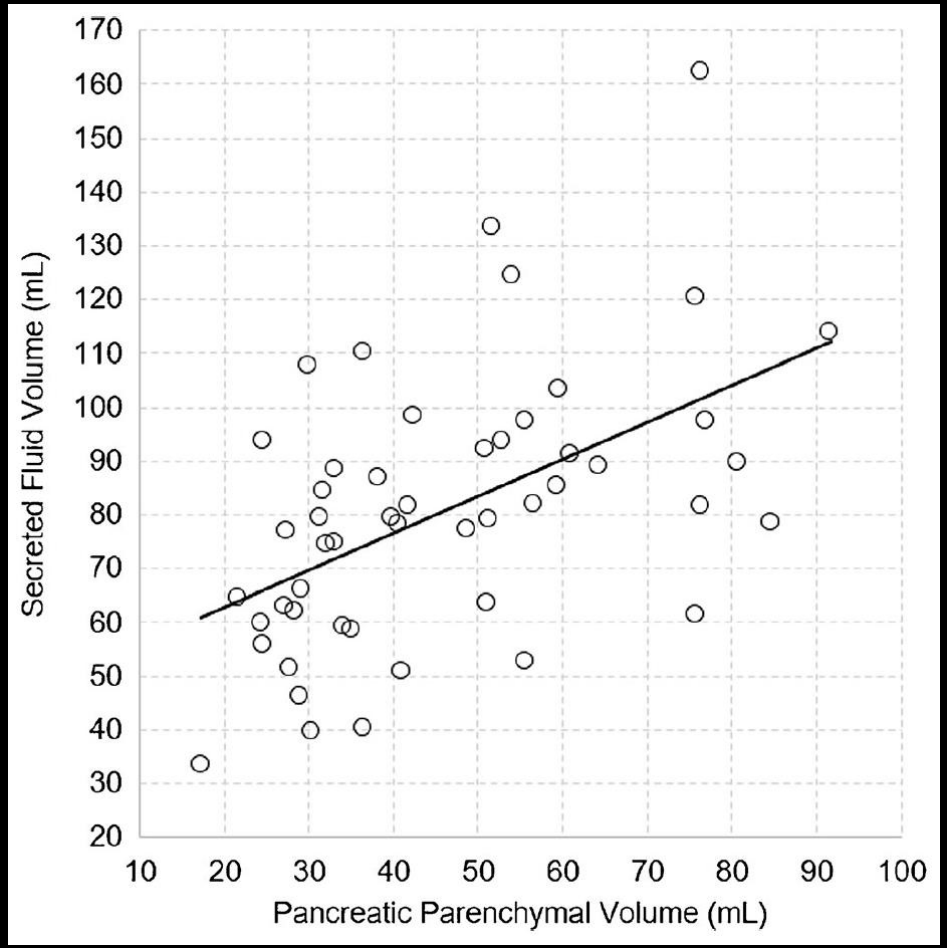
"The above findings indicate that the automation of pancreas segmentation represents a considerable challenge as the performance of current automated pancreas segmentation algorithms is suboptimal"



Parenchymal Volume

Relationship between body size & pancreas size & secretory response

- 50 healthy children
- r = 0.75 (volume:BSA)
- r = 0.51 (volume:secreted)



McCleary, et al. *Ped Rad*. 2020

Parenchymal Volume

- Currently not a lot of data for exocrine function in disease

- Data re: remnant function post whipple

Nakamura H, et al. J Surg Res. 2011 Dec;171(2):473-8.
Okano K, et al. Surgery. 2016 Mar;159(3):885-92.

Parenchymal Volume

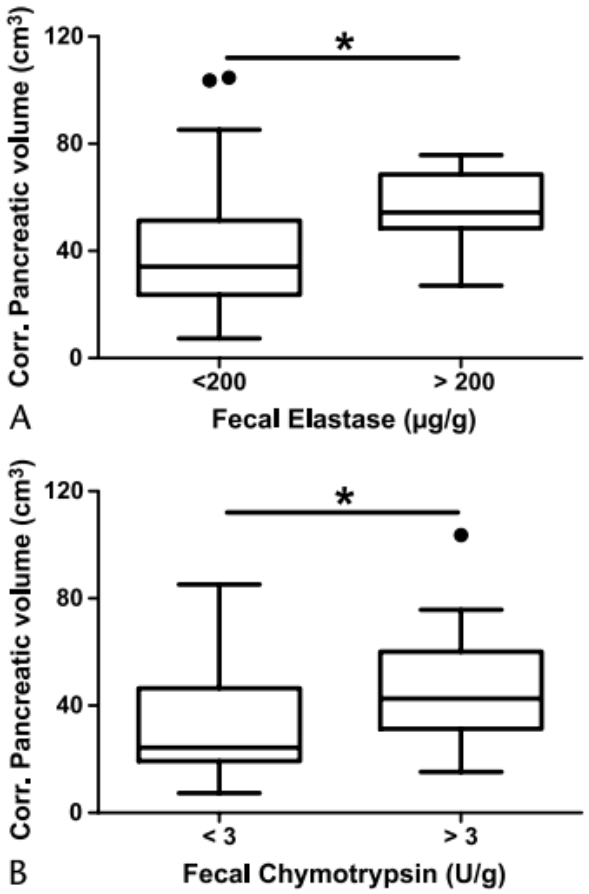


FIGURE 2. Pancreatic volume in (A) patients with low (<200 µg/g) compared with patients with normal (>200 µg/g) fecal elastase-1, (B) in patients with low (<3 U/g) compared with patients with normal (>3 U/g) fecal chymotrypsin. *$P < 0.05$.

ORIGINAL ARTICLE

Pancreas • Volume 40, Number 3, April 2011

Pancreatic Volume and Endocrine and Exocrine Functions in Patients With Diabetes

Marie-France Philippe, MD,† Salim Benabadji, MD,†‡ Laurence Barbot-Trystram, MD,§ Dominique Vadrot, MD,†‡ Christian Boitard, MD,*† and Etienne Larger, MD, PhD*†//*

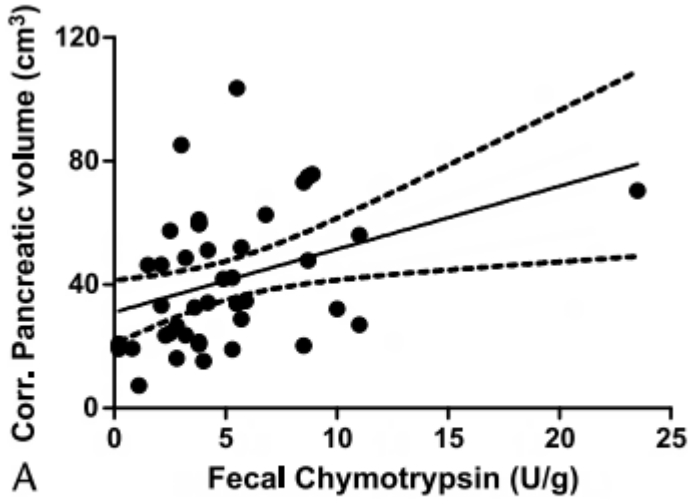


FIGURE 3. Scatter plot of pancreatic volume and (A) fecal chymotrypsin
Chymotrypsin: correlation coefficient, 0.39, $P = 0.01$

n = 28 T1 DM
n = 24 T2 DM

Parenchymal Quality

- Trans-abd US
- MRI
- CT

- EUS

- Steatosis
- Perfusion
- Other

Parenchymal Quality

PLOS ONE

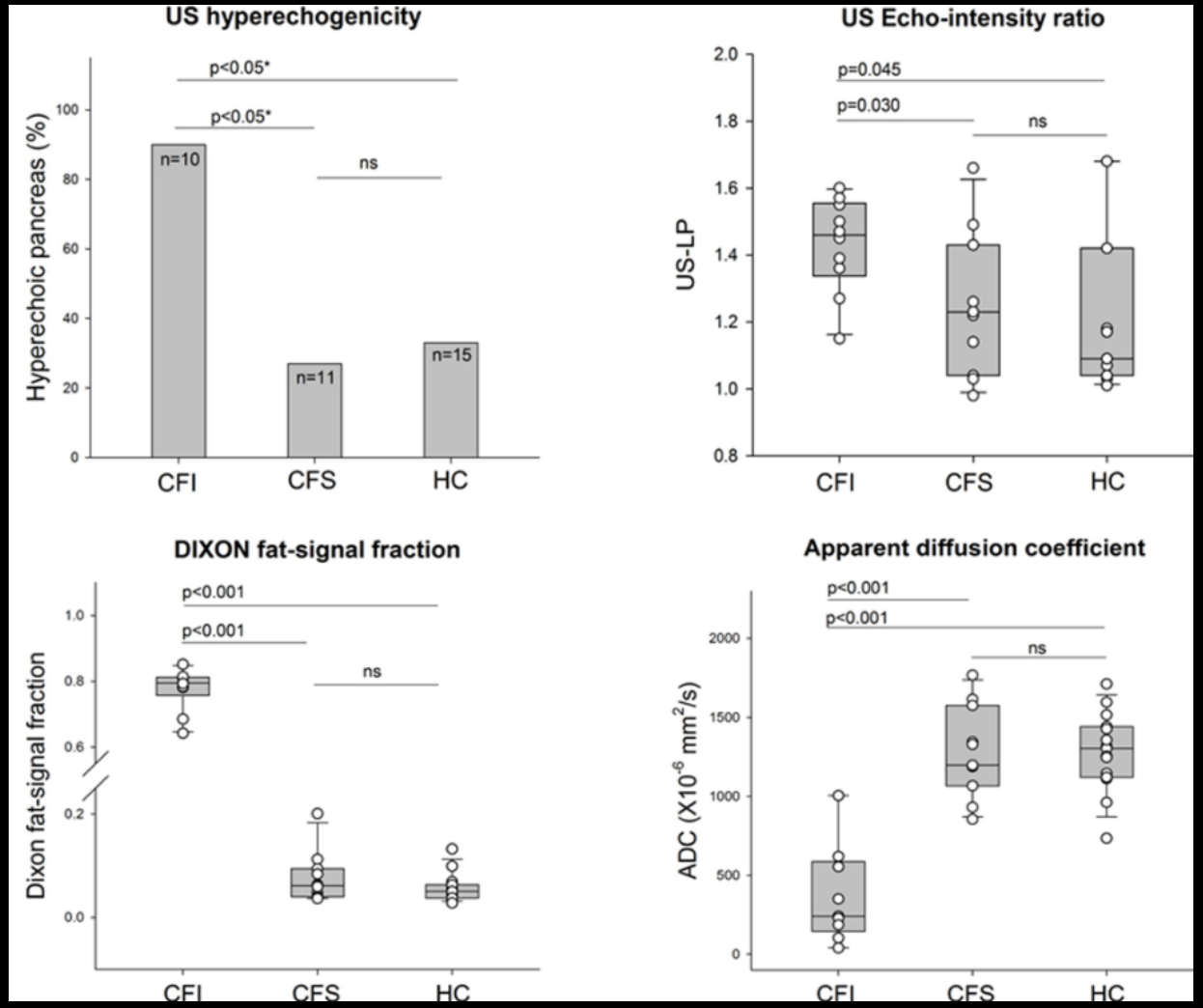
RESEARCH ARTICLE

Sonographic pancreas echogenicity in cystic fibrosis compared to exocrine pancreatic function and pancreas fat content at Dixon-MRI

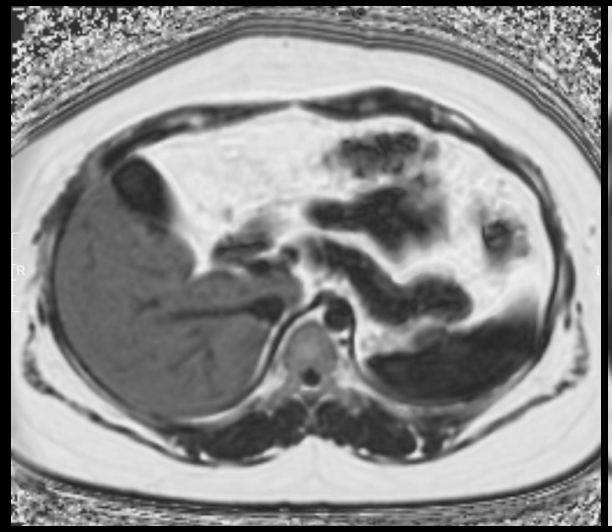
Trond Engjom[1,2]*, Giedre Kavaliauskiene[3], Erling Tjora[4,5], Friedemann Erchinger[1,6], Gaute Wathle[3], Birger Norderud Lærum[5], Pål Rasmus Njølstad[4,5], Jens Brøndum Frøkjær[7,8], Odd Helge Gilja[1,9], Georg Dimcevski[1], Ingfrid Salvesen Haldorsen[1,3]*

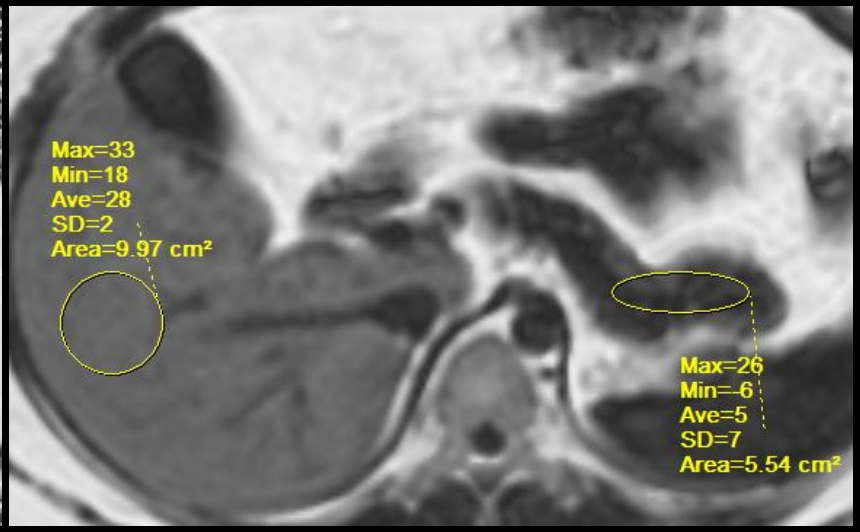
CFI = CF, insuff
CFS = CF, suff
HC = healthy control

n = 36

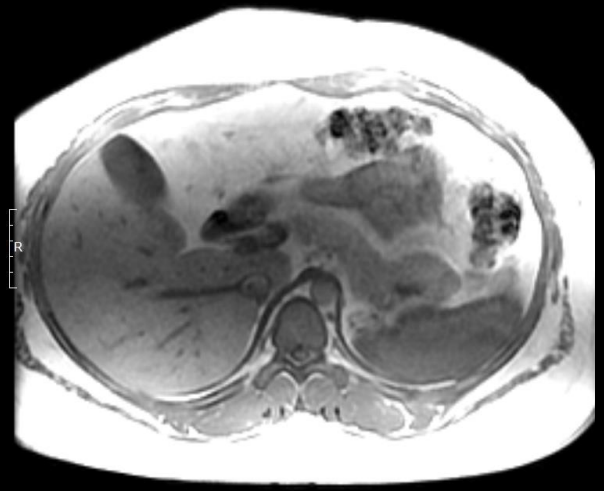


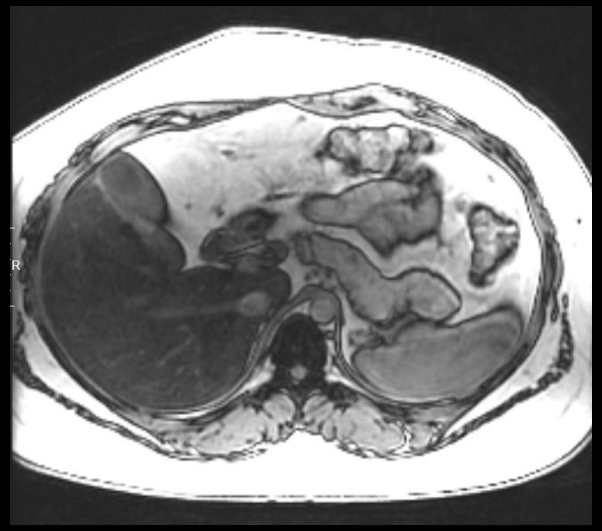
MRI Quantification of Fat





PDFF





Chemical Shift

Parenchymal Quality

ORIGINAL ARTICLE

Investigative Radiology • Volume 54, Number 7, July 2019

Pancreatic Steatosis Is Associated With Impaired Exocrine Pancreatic Function

Marie-Luise Kromrey, MD, Nele Friedrich, PhD,† Ralf-Thorsten Hoffmann, MD,‡ Robin Bülow, MD,* Henry Völzke, MD,§ Frank U. Weiss, PhD,|| Markus M. Lerch, MD,|| Utaroh Motosugi, MD, PhD,¶ and Jens-Peter Kühn, MD*‡*

MRI-PDFF

n = 1458
139 abnl

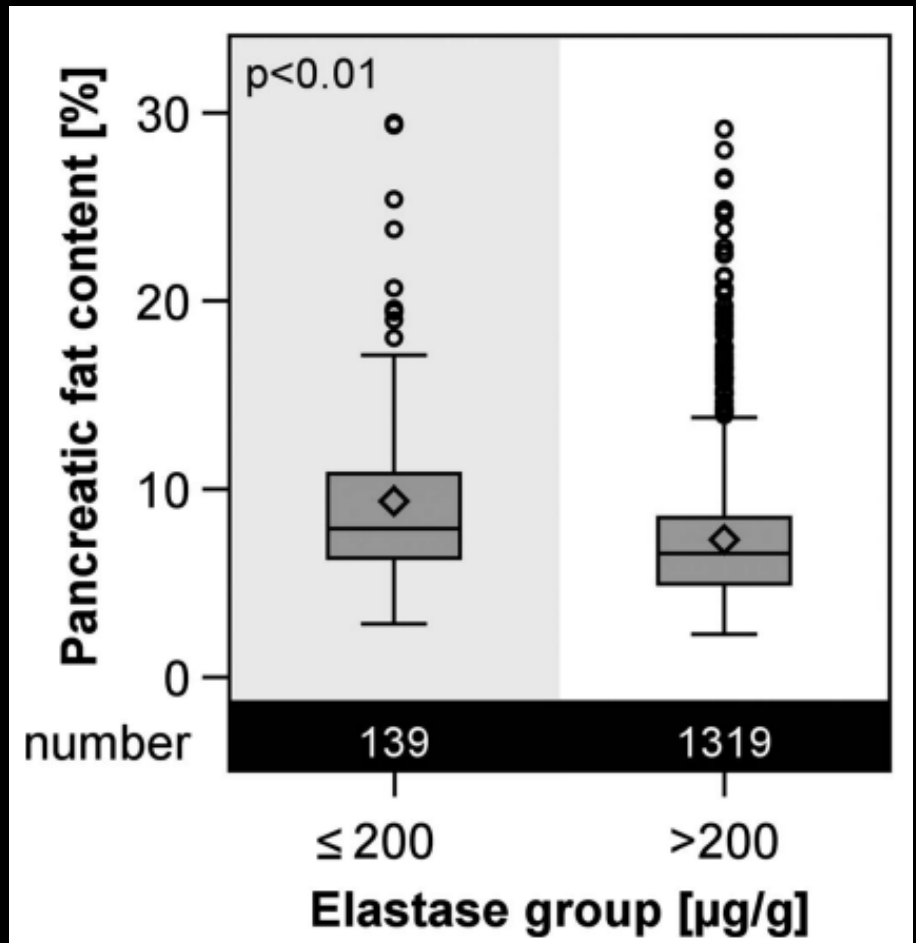


FIGURE 1. Boxplots of pancreatic fat content by exocrine pancreatic function assessed by fecal elastase levels in the whole study population. The black circles within the box indicate group means. Kruskal-Wallis test was used to compare the elastase groups.

Parenchymal Quality

- n = 45 (25 CF, 20 HC)
- Longer MTT, lower BF, lower BV in pts w/ EPI
  (decreased perfusion)
- Moderate correlation w/ ePFT (bicarb)
  - MTT: -0.58
  - BF: 0.44
  - BV: 0.45

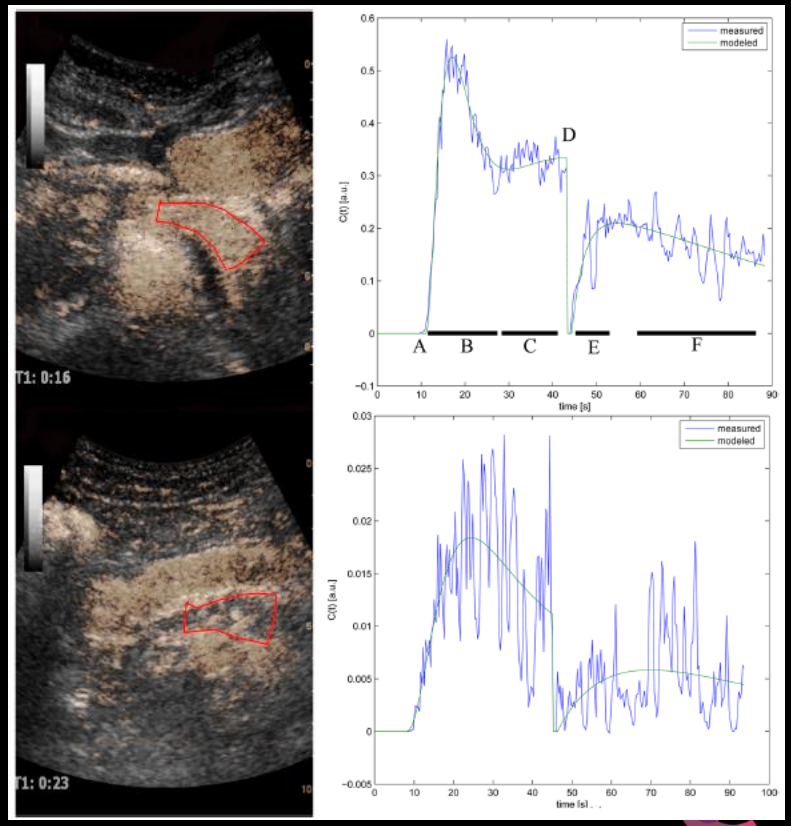
Engjom *et al. BMC Medical Imaging* (2018) 18:14
https://doi.org/10.1186/s12880-018-0259-3

BMC Medical Imaging

RESEARCH ARTICLE Open Access

Contrast-enhanced ultrasonography of the pancreas shows impaired perfusion in pancreas insufficient cystic fibrosis patients

Trond Engjom[1,2*], Kim Nylund[2], Friedemann Erchinger[1,3], Marcus Stangeland[1], Birger Norderud Lærum[4,5], Martin Mézl[6], Radovan Jiřík[7], Odd Helge Gilja[1,2] and Georg Dimcevski[1]



Parenchymal Quality

ORIGINAL ARTICLE

Pancreas • Volume 36, Number 1, January 2008

Magnetic Resonance Imaging and Magnetic Resonance Cholangiopancreatography Findings Compared With Fecal Elastase 1 Measurement for the Diagnosis of Chronic Pancreatitis

Mehmet Bilgin, MD,† Sabriye Bilgin, MD,*† N. Cem Balci, MD,‡ Amir Javad Momtahen, MD,‡ Yaşar Bilgin, MD,†§ Hans-Ulrich Klör, MD,†§ and Wigbert S. Rau, MD**

Serial Contrast-Enhanced MRI of the Pancreas:

Correlation With Secretin-Stimulated Endoscopic Pancreatic Function Test[1]

N. Cem Balci, MD, Samer Alkaade, MD, Isin E. Akduman, MD, Mehmet Bilgin, MD
Christopher P. Murdock, DO, Frank R. Burton, MD

Acad Radiol 2006; 13:1367–1372

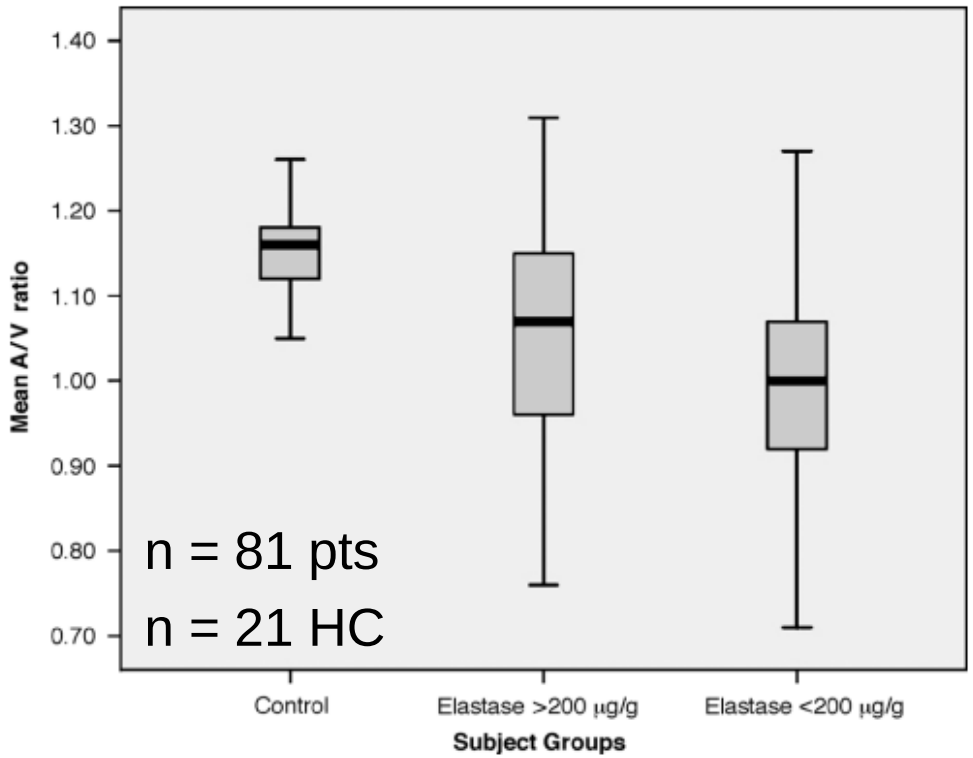


FIGURE 6. Relationship between arterial enhancement ratio and pancreatic function determined by fecal elastase 1.

Parenchymal Quality

ORIGINAL ARTICLE

Pancreas • Volume 36, Number 1, January 2008

Magnetic Resonance Imaging and Magnetic Resonance Cholangiopancreatography Findings Compared With Fecal Elastase 1 Measurement for the Diagnosis of Chronic Pancreatitis

Mehmet Bilgin, MD,† Sabriye Bilgin, MD,*† N. Cem Balci, MD,‡ Amir Javad Momtahen, MD,‡ Yaşar Bilgin, MD,†§ Hans-Ulrich Klör, MD,†§ and Wigbert S. Rau, MD**

Table 2
Correlation of CEMRI and ePFT for Pancreatitis*

	CEMRI	
ePFT (cut off 80 dEq/L)	Normal	Pancreatitis
Normal	12	7
Pancreatitis	2	9

*Numbers in the crosstab cells represent number of patients.

Serial Contrast-Enhanced MRI of the Pancreas:
Correlation With Secretin-Stimulated Endoscopic Pancreatic Function Test[1]

N. Cem Balci, MD, Samer Alkaade, MD, Isin E. Akduman, MD, Mehmet Bilgin, MD
Christopher P. Murdock, DO, Frank R. Burton, MD

Acad Radiol 2006; 13:1367–1372

n = 30

Parenchymal Quality

Other MRI measures

- T1 → Protein content
  - SIR
  - T1 relaxation time
- Diffusion → Perfusion & structure

Parenchymal Quality – T1 SIR

Abdominal Radiology

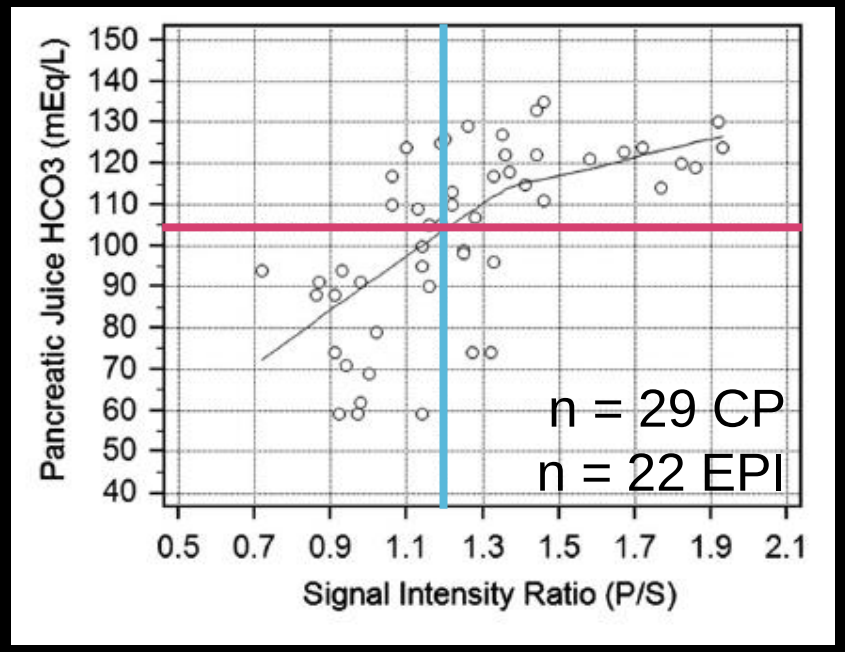
● Springer Science+Business Media New York 2016
Published online: 23 September 2016

Abdom Radiol (2017) 42:544–551
DOI: 10.1007/s00261-016-0917-2

Detection of exocrine dysfunction by MRI in patients with early chronic pancreatitis

Temel Tirkes,[1] Evan L. Fogel,[2] Stuart Sherman,[2] Chen Lin,[1] Jordan Swensson,[1] Fatih Akisik,[1] Kumaresan Sandrasegaran[1]

[1]Department of Radiology and Clinical Sciences, Indiana University School of Medicine, 550 N. University Blvd. Suite 0663, Indianapolis, IN 46202, USA
[2]Division of Gastroenterology, Department of Medicine, Indiana University School of Medicine, Indianapolis, IN, USA



Intraductal stim test

ORIGINAL ARTICLE

Pancreas • Volume 36, Number 1, January 2008

Magnetic Resonance Imaging and Magnetic Resonance Cholangiopancreatography Findings Compared With Fecal Elastase 1 Measurement for the Diagnosis of Chronic Pancreatitis

Mehmet Bilgin, MD,† Sabriye Bilgin, MD,*† N. Cem Balci, MD,‡ Amir Javad Momtahen, MD,‡ Yaşar Bilgin, MD,†§ Hans-Ulrich Klör, MD,†§ and Wigbert S. Rau, MD**

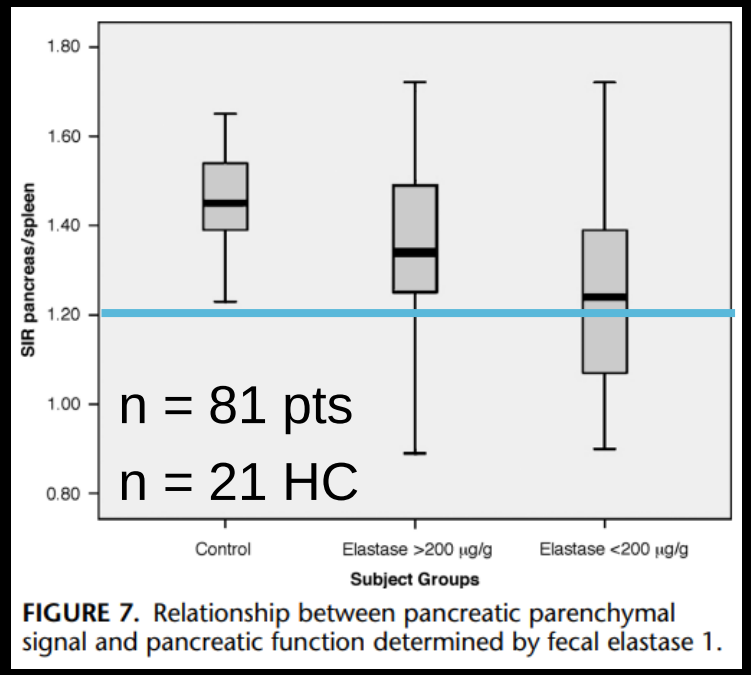
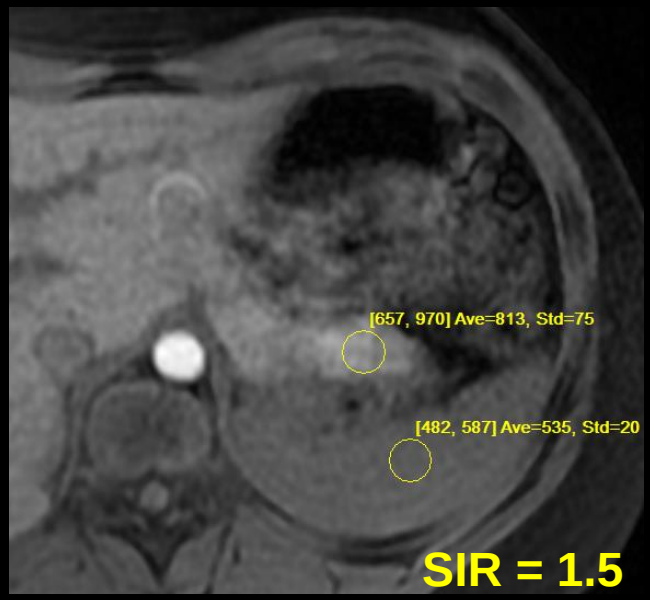


FIGURE 7. Relationship between pancreatic parenchymal signal and pancreatic function determined by fecal elastase 1.



Parenchymal Quality – T1

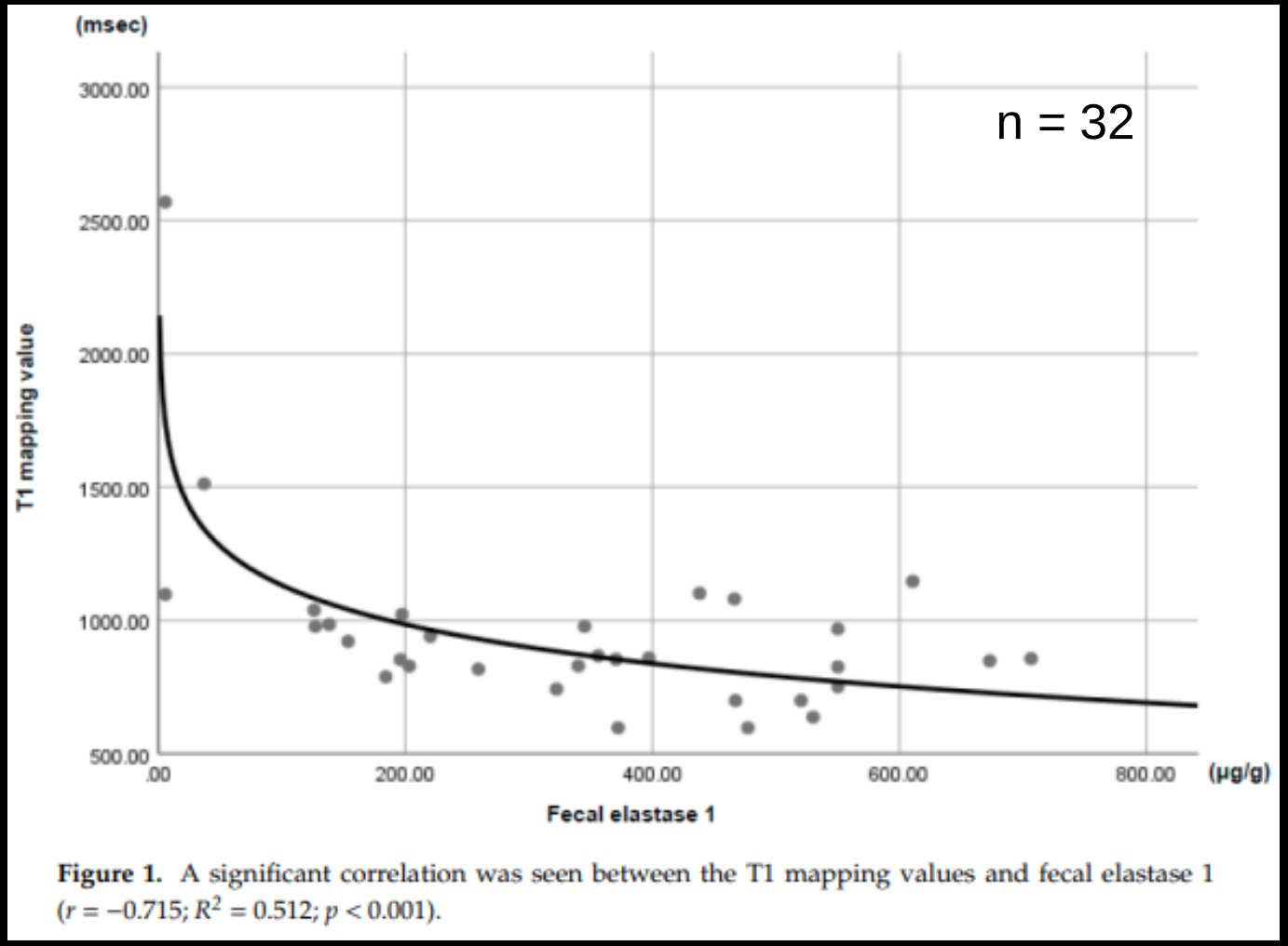


Figure 1. A significant correlation was seen between the T1 mapping values and fecal elastase 1 ($r = -0.715$; $R^2 = 0.512$; $p < 0.001$).

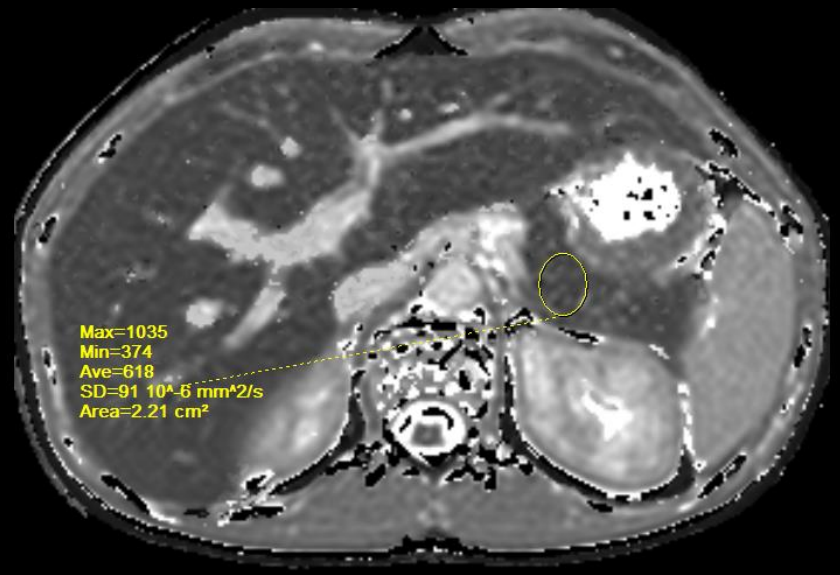
Journal of *Clinical Medicine*

MDPI

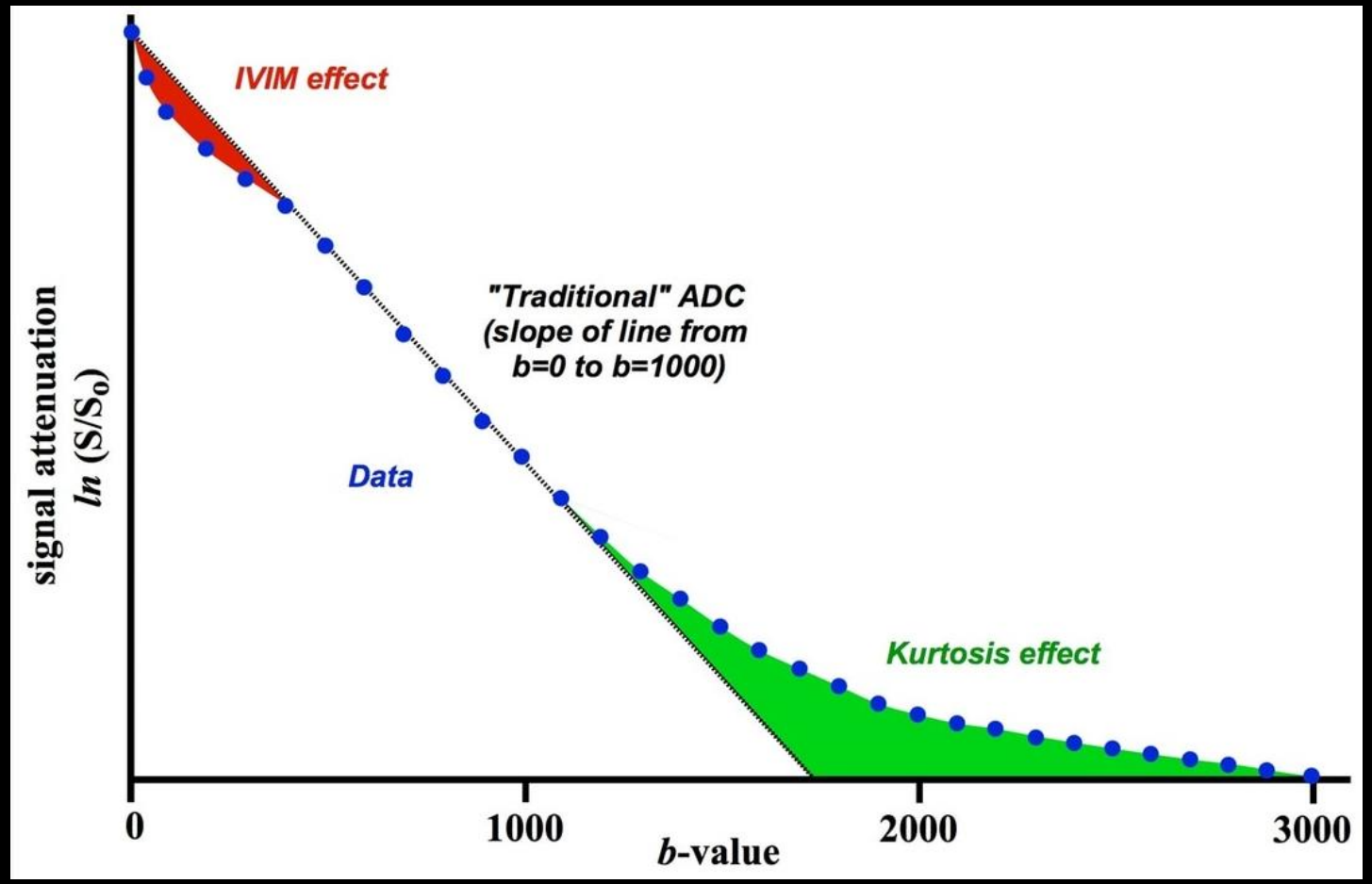
Article

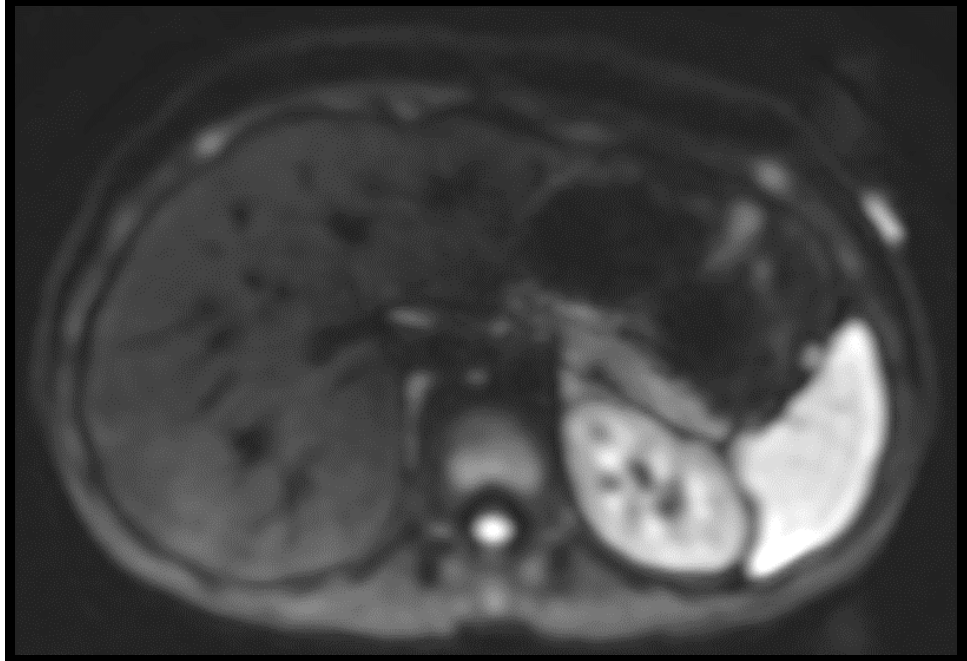
Correlation of Pancreatic T1 Values Using Modified Look-Locker Inversion Recovery Sequence (MOLLI) with Pancreatic Exocrine and Endocrine Function

Norihiro Ashihara [1,*], Takayuki Watanabe [1], Satoko Kako [1], Yasuhiro Kuraishi [1], Makiko Ozawa [1], Shohei Shigefuji [2], Keita Kanai [1], Yoko Usami [2], Akira Yamada [3], Takeji Umemura [1] and Yasunari Fujinaga [3]



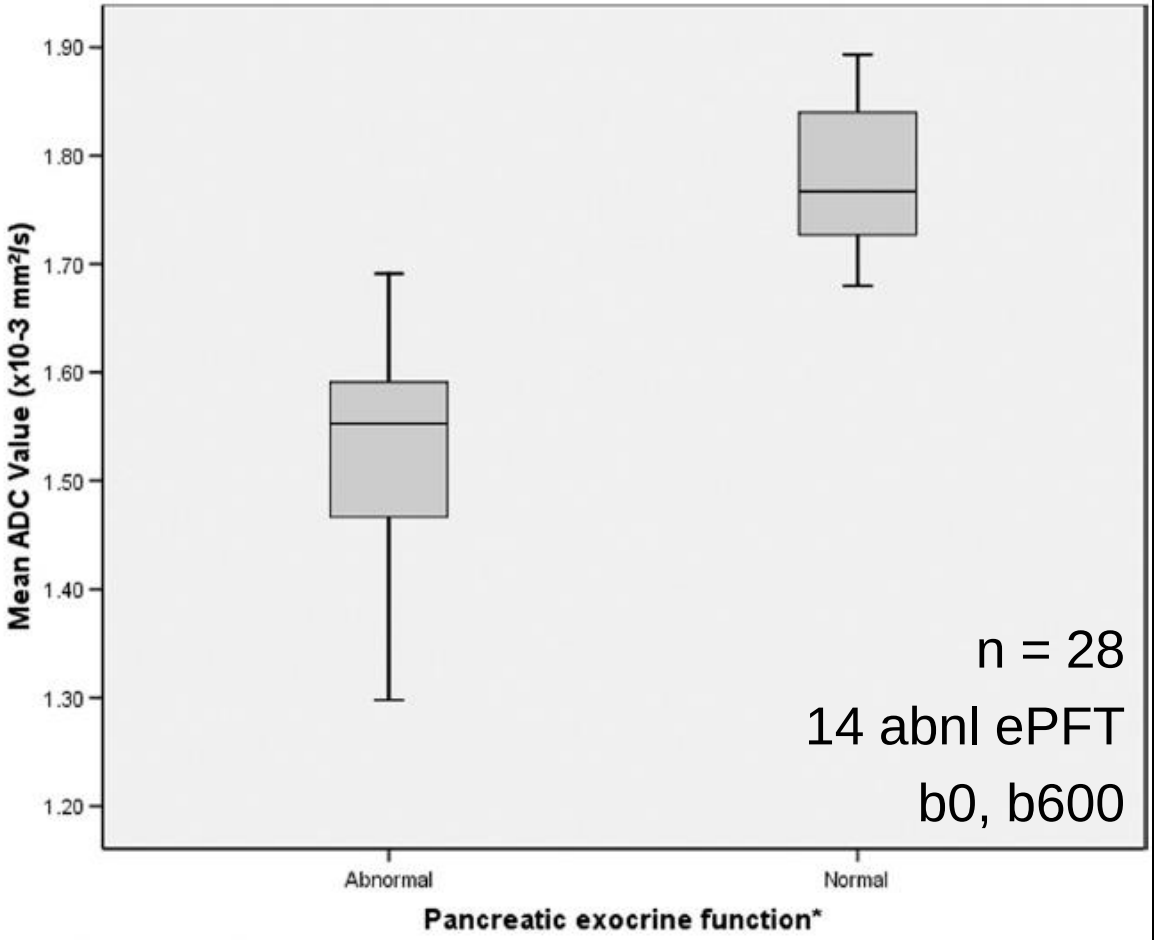
Parenchymal Quality - Diffusion





http://mriquestions.com/ivim.html

Parenchymal Quality - Diffusion



* 80 mEq/L is the cut off value for normal pancreatic exocrine function.

Figure 1. Correlation between mean apparent diffusion coefficient (ADC) values in groups with normal and abnormal pancreatic exocrine function.

Diffusion-weighted MRI of the Pancreas:
Correlation with Secretin Endoscopic Pancreatic Function Test (ePFT)[1]

N. Cem Balci, MD, Amir Javad Momtahen, MD, E. Isin Akduman, MD, Samer Alkaade, MD, Mehmet Bilgin, MD
Frank R. Burton, MD

Parenchymal Quality - Future?

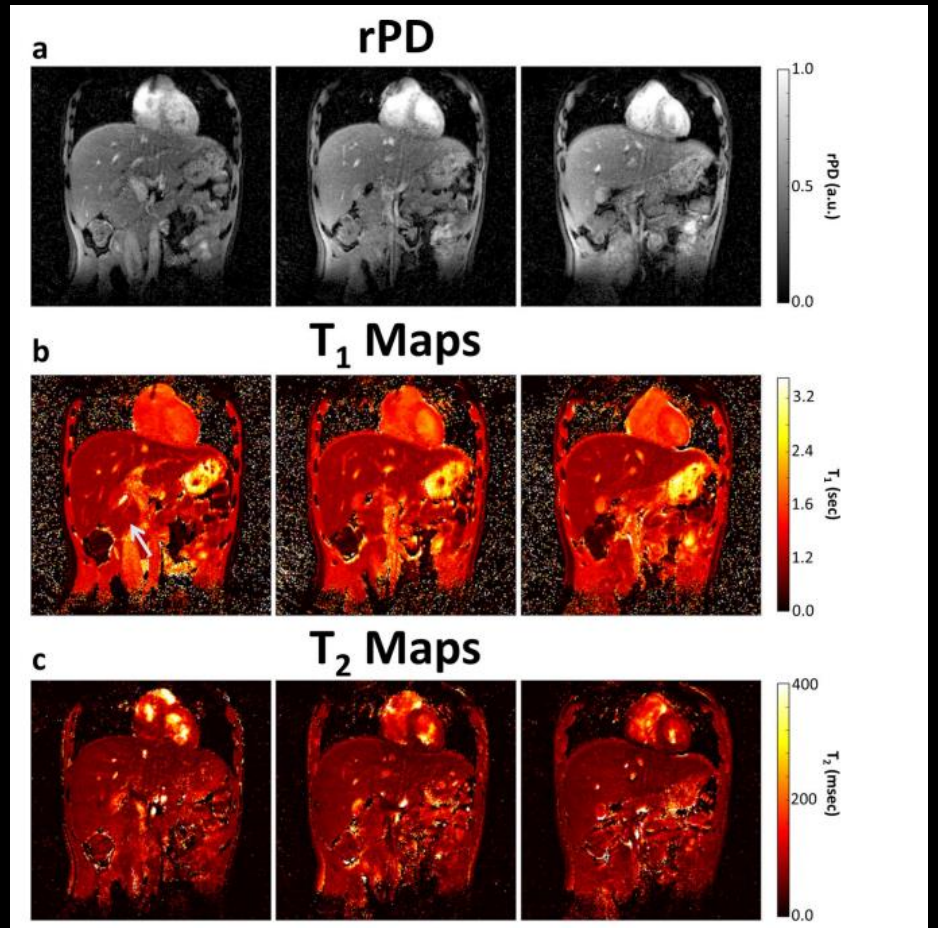


Figure 3. MRF-derived maps of (**a**) relative proton density (rPD), (**b**) T_1, and (**c**) T_2 of three consecutive slices (posterior to anterior) within the abdomen at 1.5 T. These images show the ability of MRF to obtain multiple slices through the abdomen with reasonable anatomical detail and low motion artefact. The pancreas (arrowed) has homogeneous signal throughout in both T_1 and T_2 maps, and is distinguishable due to fat/water boundaries at its periphery.

www.nature.com/scientificreports

scientific reports

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OPEN

Magnetic resonance fingerprinting of the pancreas at 1.5 T and 3.0 T

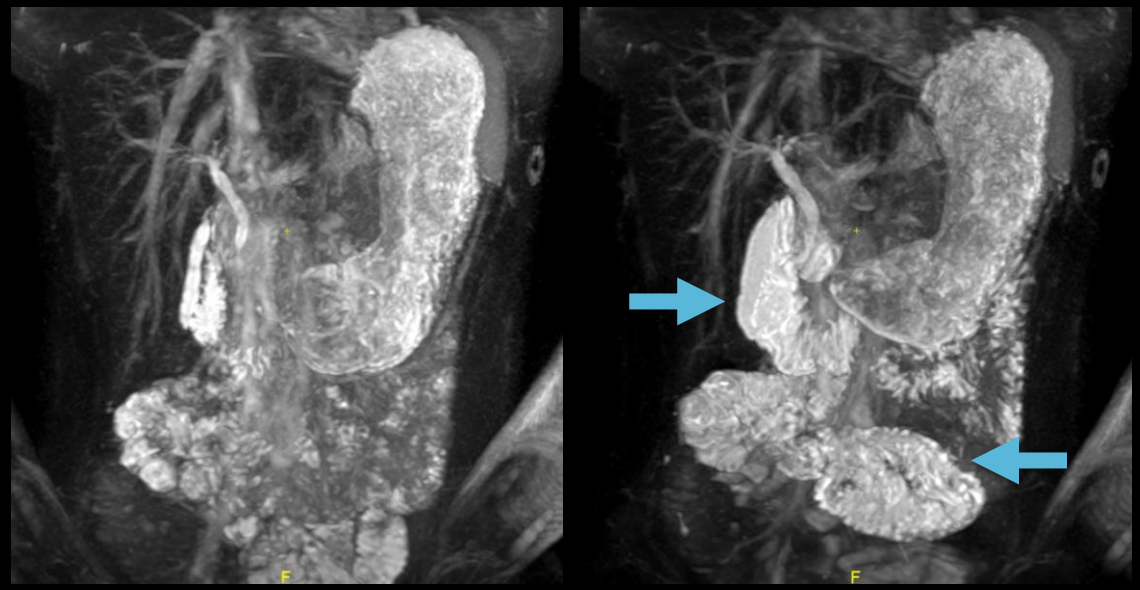
Eva M. Serrao[1,2,3], Dimitri A. Kessler[1,2], Bruno Carmo[1,2], Lucian Beer[1,2], Kevin M. Brindle[3], Guido Buonincontri[4], Ferdia A. Gallagher[1,2,3], Fiona J. Gilbert[1,2,3], Edmund Godfrey[1], Martin J. Graves[1,2], Mary A. McLean[1,2,3], Evis Sala[1,2,3], Rolf F. Schulte[5] & Joshua D. Kaggie[1,2]✉

Secretory Response

- Trans-abd US
- MRI
- Nuc Med

- EUS

- Secreted fluid volume in bowel



Pre-secretin

Post-secretin

Secretory Response - US

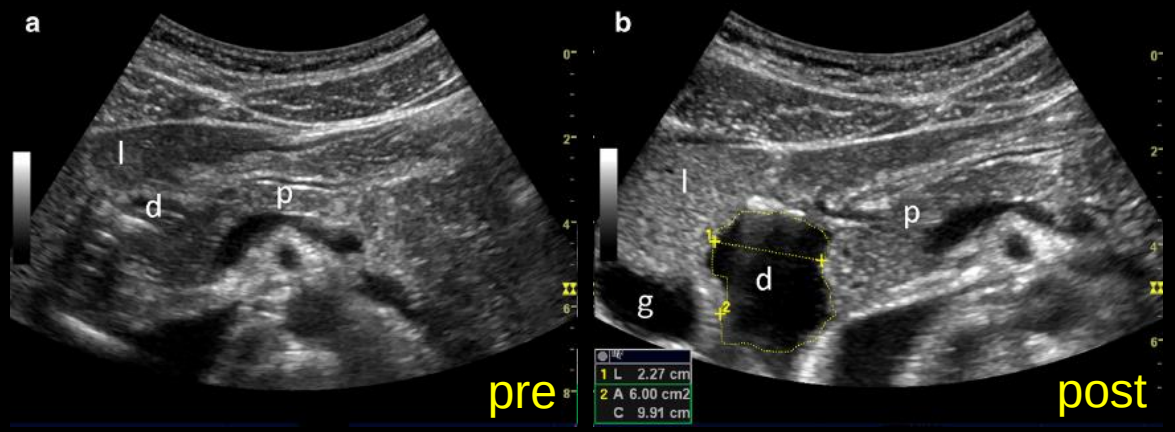
- n = 33 (11 CF suff, 10 CF insuff, 12 HC)
- Moderate correlation between US & ePFT (r = 0.63)

Eur Radiol (2018) 28:1495–1503
https://doi.org/10.1007/s00330-017-5115-2

GASTROINTESTINAL

Secretin-stimulated ultrasound estimation of pancreatic secretion in cystic fibrosis validated by magnetic resonance imaging

Trond Engjom[1,2] · Erling Tjora[3,4] · Gaute Wathle[5] · Friedemann Erchinger[1,6] · Birger N. Lærum[4] · Odd H. Gilja[1,7] · Ingfrid Salvesen Haldorsen[1,5] · Georg Dimcevski[1,2]



Secretory Response - MRI

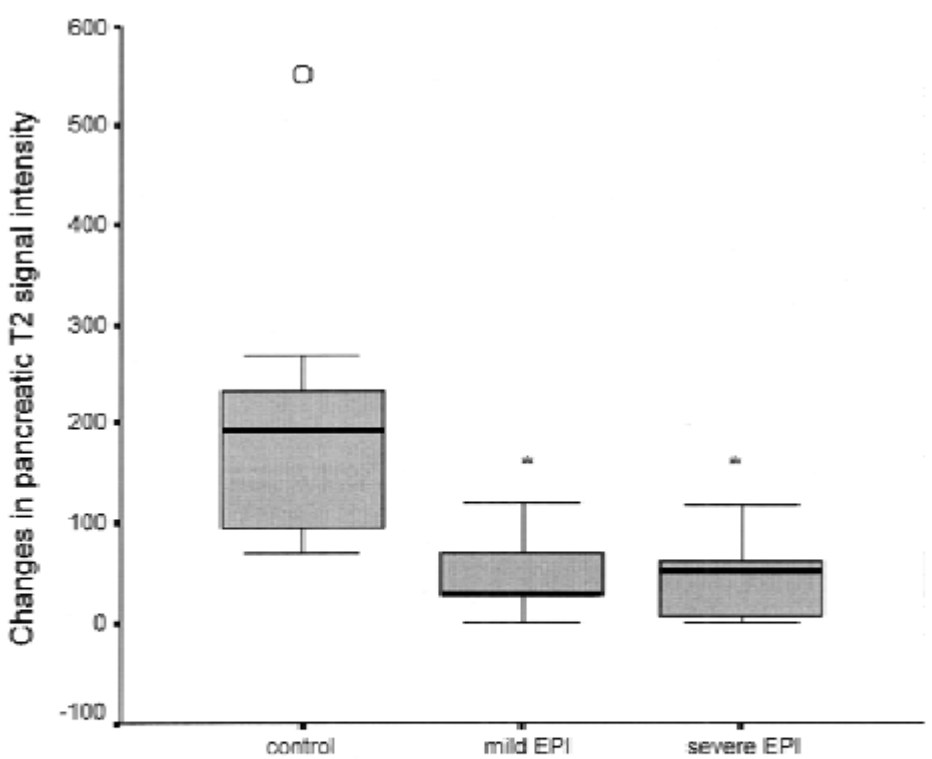


FIG. 3. Distribution of pancreatic T2 signal intensity changes after the injection of 0.5 IU/kg secretin in control volunteers and in patients with mild or severe exocrine pancreatic insufficiency (EPI). Each box extends between the upper and lower quartile with a central line at the median and whiskers out to the largest and smallest values. *Significant difference ($p < 0.05$) versus control group.

Pancreas
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Evaluation of Pancreatic Exocrine Function by Secretin-Enhanced Magnetic Resonance Cholangiopancreatography

László Czakó, *János Endes, Tamás Takács, †Krisztina Boda, and János Lonovics

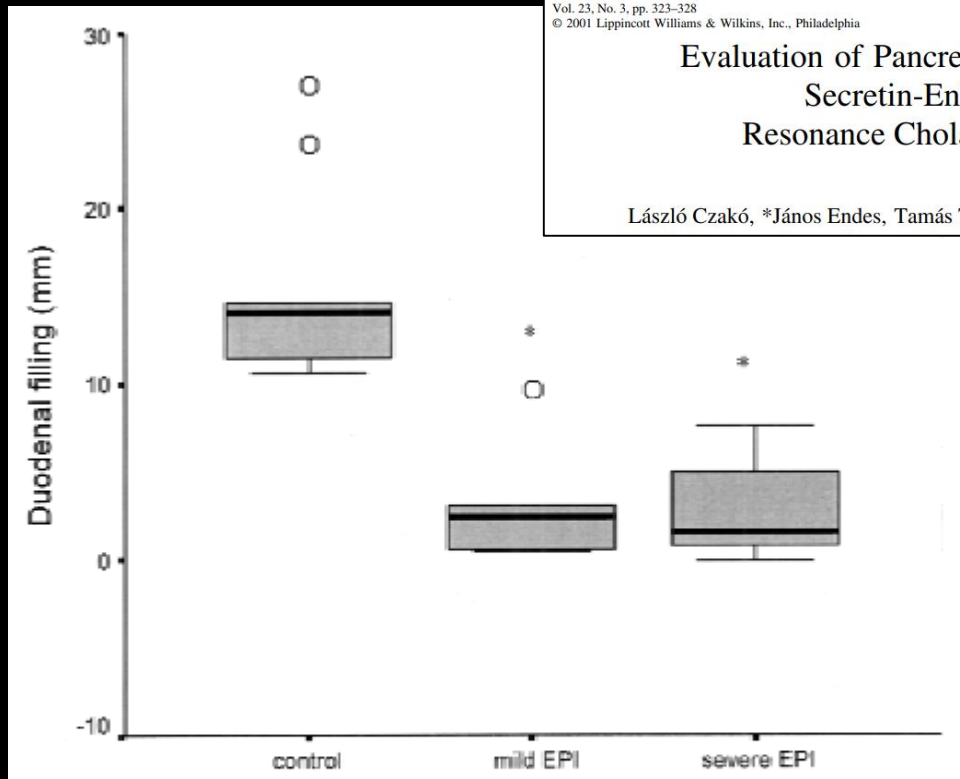
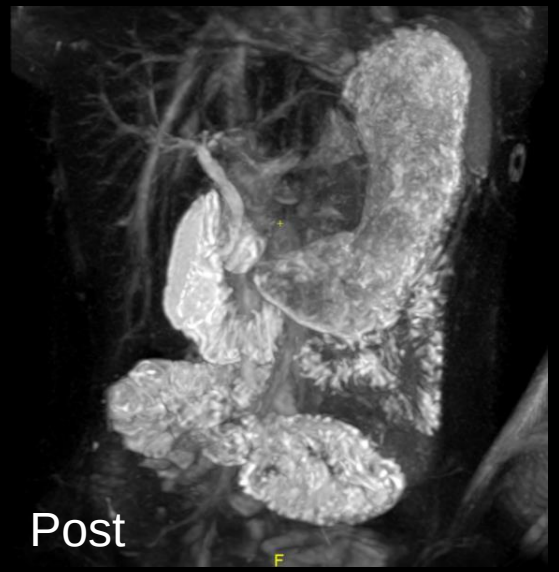
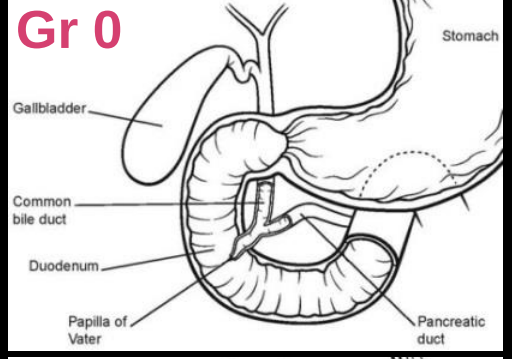


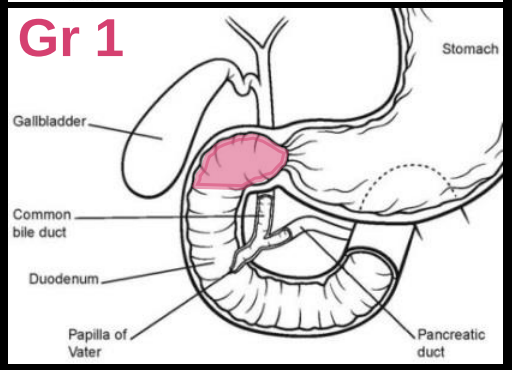
FIG. 4. Distribution of duodenal filling after the injection of 0.5 IU/kg secretin in control volunteers and in patients with mild or severe exocrine pancreatic insufficiency (EPI). Each box extends between the upper and lower quartile with a central line at the median and whiskers out to the largest and smallest values. *Significant difference ($p < 0.05$) versus control group.

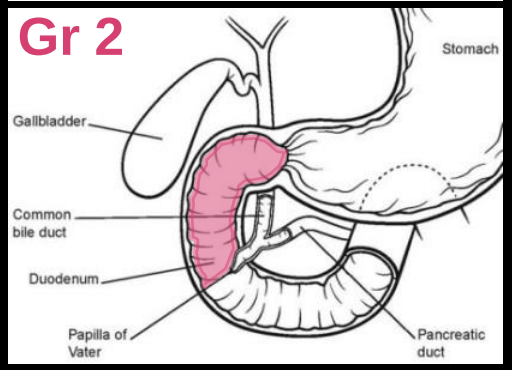
n = 20 pts

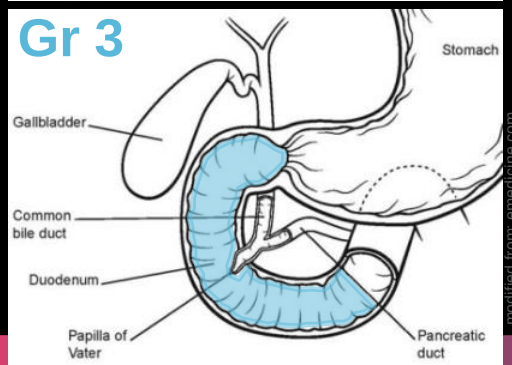
n = 10 HC











modified from: emedicine.com

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Chronic Pancreatitis: Evaluation of Pancreatic Exocrine Function with MR Pancreatography after Secretin Stimulation[1]

Radiology 2000; 215:358–364

n = 49 pts

n = 28 HC

TABLE 3
PPJ Parameters according to Grade of Duodenal Filling

Duodenal Filling Grade	Maximal Secretory Volume (mL/min)	Total Secretory Volume (mL/10 min)	Maximal Bicarbonate Concentration (mEq/L)	Maximal Bicarbonate Output (μEq/min)
1	0.7 ± 0.2*	4.5 ± 1.2*	63.0 ± 5.0*	38.4 ± 15.2*
2	2.6 ± 0.8	21.4 ± 6.9	96.0 ± 4.2	241.5 ± 84.0
3	3.7 ± 0.5	28.7 ± 3.9	105.2 ± 3.8	387.1 ± 71.3

Note.—Data are the mean plus or minus the standard error.
* Parameter was significantly lower than that in patients with grade 2 or 3 duodenal filling ($P < .05$).

Matos C, et al. Radiology. 1997 May;203(2):435-41..

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BRIEF ARTICLE

Quantification of pancreatic exocrine function of chronic pancreatitis with secretin-enhanced MRCP

Yun Bian, Li Wang, Chao Chen, Jian-Ping Lu, Jia-Bao Fan, Shi-Yue Chen, Bing-Hui Zhao

Table 2 Results in normal and reduced duodenal filling

	n	FE-1 (μg/g)	PFR (mL/min)	PT (min)
Normal DF (grade 3)	40	453.64 ± 162.74	7.16 ± 2.34	7.28 ± 2.56
Reduced DF (grade 1, 2)	13	285.59 ± 158.03	4.71 ± 1.92	9.61 ± 3.57
P value		0.002	0.001	0.012

FE-1: Fecal elastase-1; PFR: Pancreatic flow output rate; PT: Peak time; DF: Duodenal filling.

Original Research

JOURNAL OF MAGNETIC RESONANCE IMAGING 31:601–606 (2010)

MRI and S-MRCP Findings in Patients With Suspected Chronic Pancreatitis: Correlation With Endoscopic Pancreatic Function Testing (ePFT)

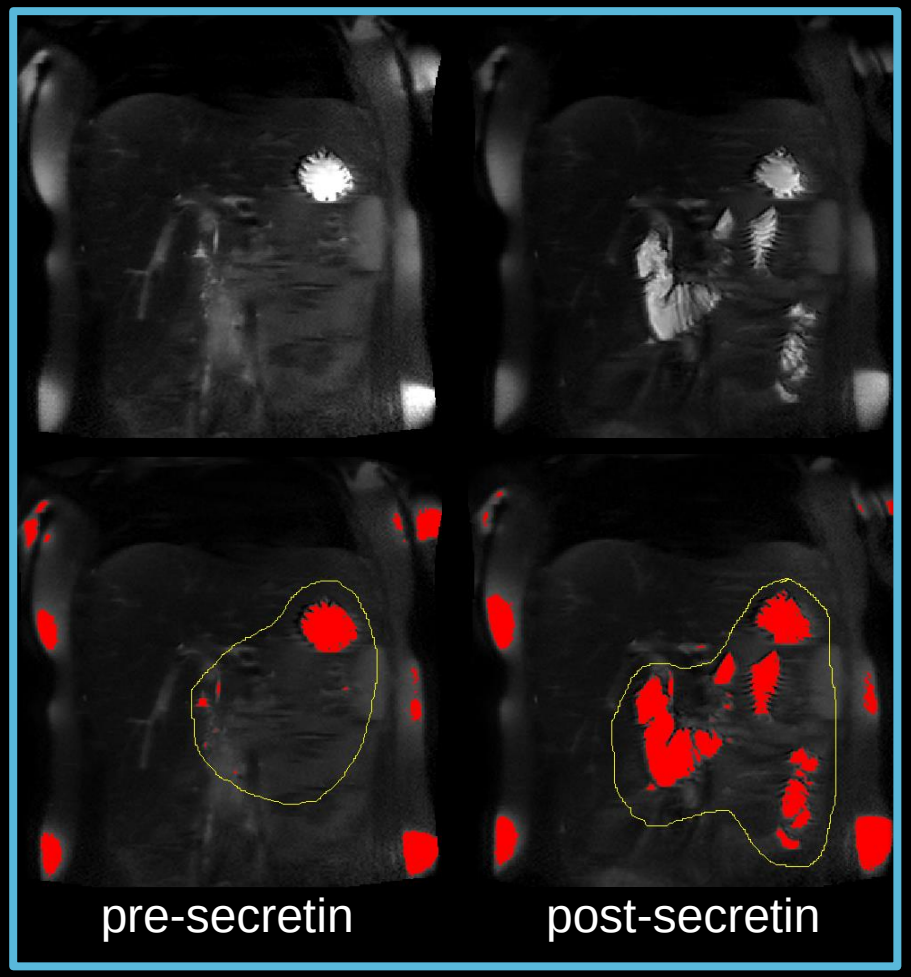
N. Cem Balci, MD,[1]* Adam Smith, MD,[1] Amir Javad Momtahen, MD,[1] Samer Alkaade, MD,[2] Rana Fattahi, MD,[1] Syed Tariq, MD,[2] and Frank Burton, MD[2]

Table 3
Frequency of Findings on S-MRCP

		Normal Pancreatic Exocrine Function HCO_3**			Diminished Pancreatic Exocrine Function HCO_3**	
Baseline MRCP*						
Cambridge 1	15	62%	112	5	42%	65
Cambridge 2	3	12.60%	108	4	33%	73
Cambridge 3	3	12.60%	113			
Cambridge 4	3	12.60%	115	3	25%	60
Cambridge 5						
Duodenal Filling on S-MRCP						
Grade 1				1	9%	38
Grade 2				11	91%	68
Grade 3	24	100%	112			

*Cambridge Classification.
**mEq/L.

Secretory Response - Volume



Norms exist

Gastrointestinal Imaging • Original Research

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Markus M. Lerch[2]
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Secretin-Stimulated MRCP in Volunteers: Assessment of Safety, Duct Visualization, and Pancreatic Exocrine Function

AJR:202, January 2014

Prospective Assessment of Normal Pancreatic Secretory Function Measured by MRI in a Cohort of Healthy Children

Andrew T. Trout, MD[1,2], Suraj D. Serai, PhD[2], Lin Fei, PhD[3], Qin Sun, MPH[3] and Maisam Abu-El-Haija, MD[4]

PANCREAS

Secretion correlated with size & parenchymal volume

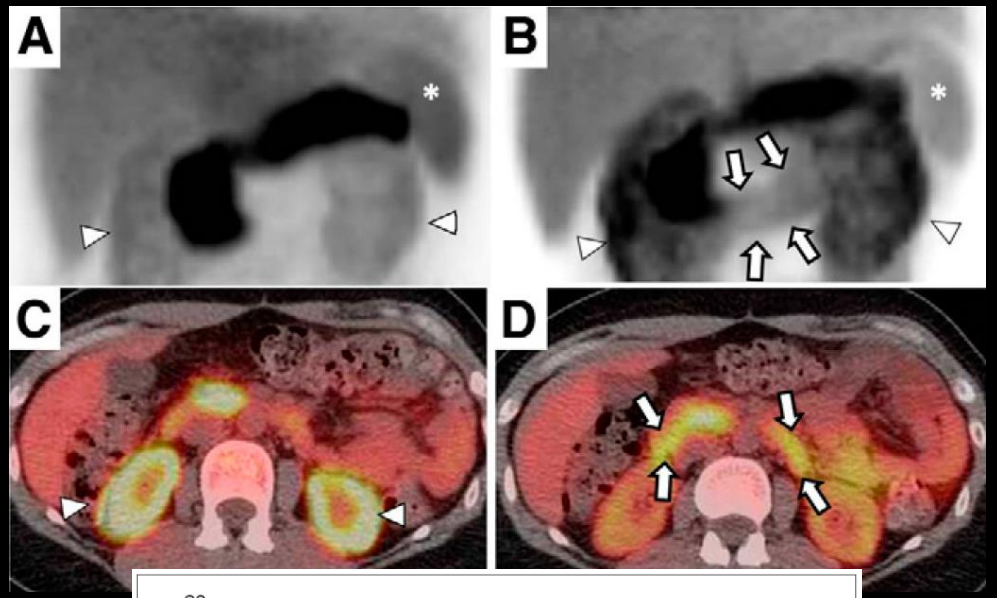
Secretory Response

BRIEF COMMUNICATION

An Exocrine Pancreatic Stress Test with ^{11}C-Acetate PET and Secretin Stimulation

Joo Hyun O[1], Martin A. Lodge[1], Sanjay Jagannath[2], Jonathan M. Buscaglia[3], Yetunde Olagbemiro[1], and Richard L. Wahl[1]

- Pilot study (n=5)
- C-11 Acetate converted to bicarb
- Post secretin
  - ↑ parenchymal SUV (?perfusion)
  - ↑ duodenal SUV (excretion)



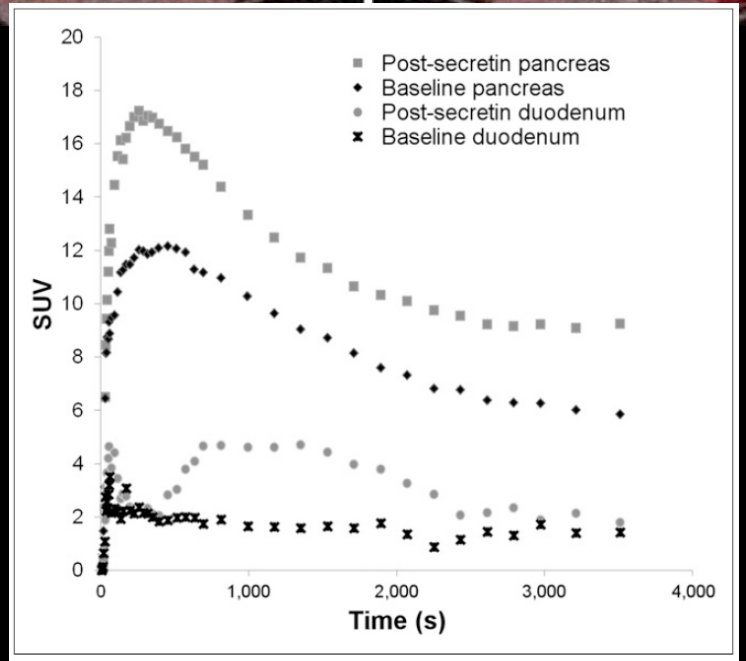
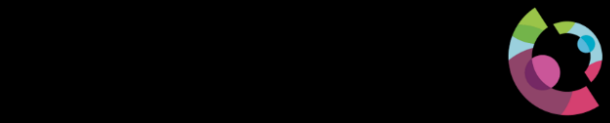


FIGURE 2. Time–activity curves: changes in SUV over time derived from dynamic ^{11}C-acetate PET studies before and after secretin stimulation in healthy volunteer.

Summary

- Multiple imaging methods / options to understand exocrine function
- Need clarity on reference standard
- Relationships not clean
- Likely will need multiparametric approach
- Lots of work to be done!



THANK YOU

@AndrewTroutMD

Cincinnati Children's
changing the outcome together