Psoas CT Attenuation and Fatty Infiltration Rate Predict Incisional Hernia After Appendicectomy

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Research article

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Abstract

Background Incisional hernia (IH), especially giant incisional hernia negatively affects a patient's quality of life. Previous literatures often used muscle area measured by CT to assess loss of muscle mass and to estimate its relationship with diseases. For now, a few literatures have discussed potential effect of psoas muscle area on IH, while very limited attention has been paid to the association between psoas fatty infiltration and incidence of IH. In this study, we aimed to investigate if psoas CT measurement parameters, including average CT attenuation, fatty infiltration rate and psoas muscle index, were associated with IH.

Methods Adult patients (> 18 years old) who had a history of appendicectomy and underwent CT examination in Beijing Chaoyang hospital from January 2018 to December 2019 were enrolled. All patients were classified into IH group and non-IH group. Psoas CT attenuation, fatty infiltration rate (FIR) and psoas muscle index (PMI) were measured or calculated. Sarcopenia was defined according to PMI. Differences in indices between the two groups were compared. Logistic regression model was applied to assess the effects of psoas CT measurement parameters on the occurrence of IH.

Results 120 consecutive patients were included in this study. Psoas CT attenuation ($p = 0.031$) and PMI ($p = 0.042$) in IH group were significantly lower than those in non-IH group, and FIR in IH group was significantly higher than that in non-IH group ($p < 0.001$). Psoas CT attenuation, FIR, PMI, age, gender and smoking were significant factors in univariate logistic regression analysis. After adjusting for confounding factors, multivariate logistic regression analysis demonstrated that psoas CT attenuation was an independent protective factor ($p = 0.042$), and FIR an independent risk factor ($p = 0.018$); while PMI ($p = 0.118$) and sarcopenia ($p = 0.663$) showed no significant effect on incidence of IH.

Conclusion Decreased CT attenuation and increased FIR of psoas are risk factors for IH after appendectomy.

Background

Since incisional hernia (IH), especially giant incisional hernia, negatively affects a patient's quality of life, body image and even cardiopulmonary function, it has received increasingly clinical attention. Computed tomography (CT) is a major preoperative examination for patients with abdominal incisional hernia. Besides accurately and intuitively displaying specific contents and sizes of hernias [1], helping to estimate potential risk of intestinal adhesion or intestinal ischemia [2, 3], CT scan of the abdomen can provide information about lumbar and dorsal muscle, such as muscle area, CT density and extent of fatty infiltration. Previous literatures often used muscle area measured by CT to assess loss of muscle mass and to estimate its relationship with diseases [4]. However, area alone may be inadequate when evaluating the muscle. Because in addition to volume change, muscle loss is accompanied by fatty infiltration [5, 6]. For now, a few literatures have discussed potential effect of psoas muscle area on IH, while very limited attention has been paid to the association between psoas fatty infiltration and incidence of IH. In this study, by measuring psoas parameters on CT images in IH and non-IH patients after appendectomy, we aimed to investigate if psoas CT measurement parameters, including average CT attenuation, fatty infiltration rate (FIR) and psoas muscle index (PMI), were associated with IH.

Methods

Adult patients (> 18 years old) who had a history of appendicectomy and underwent CT examination in Beijing Chaoyang hospital from January 2018 to December 2019 were enrolled. Exclusion criteria were (a) various factors that affect muscle mass, including malignant tumors, taking medicine such as glucocorticoids or thyroxine, endocrine diseases, chronic exercise limitations, organ failure and uncontrolled cardiopulmonary diseases; (b) lumbosacral transitional anatomy. The patients were classified into IH group (confirmed clinically or surgically) and non-IH group. Data on age, gender, height, weight, smoking, hypertension and diabetes were recorded. Body mass index (BMI, kg/m^2) was calculated by dividing the weight in kilograms by the square of the height in meters. The Research Ethics Review Committee of Beijing Chaoyang hospital had reviewed and approved this study.

CT scan and image measurements

CT scan was performed on gemstone CT spectroscopy (Discovery CT 750 HD, GE Healthcare). Imaging protocols included: 120kVp, tube current modulation, pitch 0.984, slice thickness 5 mm, slice spacing 5 mm. Reconstructed image with 0.625 mm slice thickness was obtained for further analysis. On GE AW 4.6 workstation, bilateral psoas muscles were measured separately at the level of the third lumbar vertebra (L3), on which both the transverse processes were visible, as previously described [7]. By manually outlining the left and the right psoas, cross-sectional area (CSA, cm^2), CT attenuation, and FIR (%) based on a Hounsfield unit (HU) threshold for adipose tissue (-190 HU to -30 HU) were automatically calculated. PMI (bilateral CSA adjusted for a patient's height squared, cm^2/m^2), bilateral mean CT attenuation and FIR were calculated. According to previous literature about Asian [8], a male PMI < $5.923 cm^2/m^2$ or a female PMI < $3.999\ cm^2/m^2$ was defined as sarcopenia.

Statistical analysis

Quantitative data were either represented as mean ± standard deviation (SD) or median with interquartile range (IQR). Qualitative data were reported as counts and percentages. Quantitative variables were compared between the two groups by using independent sample t-test or Wilcoxon signed rank test. Qualitative variables were compared using chi-square test. Logistic regression model was created to assess potential influence of psoas muscle measurement parameters on risk of IH. All the above statistical analyses were performed using SAS version 9.1 (SAS, Cary, NC, USA). The MedCalc software was used for receiver operating characteristic (ROC) curve analysis to compare diagnostic efficiency of CT attenuation and FIR for IH. Statistical significance was defined at a $p < 0.05$ (2-sided).

Results

120 consecutive patients were included in this study.

Clinical data and CT measurements between IH and non-IH groups (Table 1)

Table 1
Clinical data and CT measurements between IH and non-IH groups

	IH (n = 60)	non-IH (n = 60)	Statistic	*P* value
CT attenuation (HU)	40.2 ± 7.6	43.0 ± 6.8	-2.18	0.031[a]
FIR (%)	4.3 (3.1–5.5)	3.1 (2.0-4.2)	4310	< 0.001[b]
PMI (cm^2/m^2)	5.0 (4.1–5.9)	5.9 ± 1.9	3242	0.042 [b]
Age(y)	65.2 ± 11.9	59.8 ± 14.1	2.26	0.026 [a]
Male (%)	36.70	55.00	4.062	0.044[c]
BMI (kg/m^2)	26.1 (23.9–27.8)	25.6 (23.4–27.5)	3374.5	0.381 [b]
Smoking (%)	81.70	58.30	7.778	0.005 [c]
Hypertension (%)	50.00	46.67	0.134	0.715 [c]
Diabetes (%)	18.30	20.00	0.054	0.817 [c]
a: independent sample t-test; b: Wilcoxon signed rank test; c: chi-square test				
IH Incisional hernia, *FIR* Fatty infiltration rate, *PMI* Psoas muscle index; *BMI* Body mass index				

Psoas CT attenuation (t = -2.18, $p = 0.031$) and PMI (S = 3242, $p = 0.042$) in IH group were significantly lower than those in non-IH group, and FIR in IH patients was statistically higher than that in non-IH patients (S = 4310, $p < 0.001$). IH patients were, on average, 5 years older than non-IH patients (t = 2.26, $p = 0.026$). In IH group, more than half was women (63.3%); by contrast, female accounted for only 45.0% in non-IH group ($\chi^2 = 4.06$, $p = 0.044$). In IH group, the proportion of smokers was 1.4 times of that in non-IH group ($\chi^2 = 7.78$, $p = 0.005$). However, BMI, diabetes and hypertension were comparable between the two groups ($p > 0.05$).

Logistic regression analysis of risk factors of IH

Psoas CT attenuation, FIR, PMI, age, gender and smoking were associated with IH in univariate logistic regression analysis (Table 2). After adjusting for age, gender and smoking in multivariate logistic regression analysis, CT attenuation was an independent protective factor (OR 0.94, 95% CI 0.88–0.99, $p = 0.042$), and FIR was an independent risk factor (OR 1.34, 95% CI 1.05–1.70, $p = 0.018$). By contrast, PMI

(OR 0.78, 95% CI 0.56–1.07, $p = 0.118$) and sarcopenia (OR 0.84, 95% CI 0.38–1.87, $p = 0.663$) showed no effect on IH (Table 3). As shown in Fig. 2, area under the curve (AUCs) of CT attenuation and FIR are 0.604 (95% CI 0.51–0.69), 0.689 (95% CI 0.60–0.77) respectively. FIR had significantly higher diagnostic efficacy than CT attenuation (Z = 2.610, $p = 0.009$). The cutoff value of FIR was 3.8%, with a sensitivity of 58.33% and a specificity of 73.33%. The cutoff value of CT attenuation was 43.5 HU, with a sensitivity of 66.67% and a specificity of 51.67%.

Table 2
Univariate logistic regression analysis

	OR	**95% CI**	***P* value**
CT attenuation	0.95	0.90–0.99	0.034
FIR	1.35	1.10–1.66	0.004
PMI	0.76	0.60–0.96	0.021
Sarcopenia	0.80	0.37–1.71	0.559
Age	1.03	1.00-1.06	0.028
Gender	2.11	1.02–4.39	0.045
BMI	1.00	0.91–1.10	0.972
Smoking	3.18	1.39–7.30	0.006
Hypertension	1.14	0.56–2.34	0.715
Diabetes	0.90	0.36–2.23	0.817

FIR Fatty infiltration rate, *PMI* Psoas muscle index

Table 3
Multivariate logistic regression analysis

		OR	95% CI	*P* value
CT attenuation		0.94	0.88–0.99	0.042
	Age	0.75	0.24–2.32	0.614
	Gender	0.96	0.38–2.45	0.928
	Smoking	3.31	1.19–9.22	0.022
FIR		1.34	1.05–1.70	0.018
	Age	0.77	0.25–2.34	0.647
	Gender	0.85	0.32–2.21	0.732
	Smoking	2.75	1.00-7.53	0.049
PMI		0.78	0.56–1.07	0.118
	Age	1.07	0.38–2.98	0.897
	Gender	0.71	0.23–2.22	0.556
	Smoking	3.06	1.11–8.44	0.031
Sarcopenia		0.84	0.38–1.87	0.663
	Age	1.29	0.47–3.56	0.621
	Gender	1.26	0.52–3.07	0.612
	Smoking	2.73	1.01–7.39	0.047

FIR Fatty infiltration rate, *PMI* Psoas muscle index

Discussion

Incisional hernia is a frequent and well described complication to abdominal surgery, which causes discomfort, pain, and reduction of quality of life. Nearly 350,000 hernia repairs are performed annually, costing approximately $3 billion dollars in the USA [9]. The main known risk factors for IH development include surgical site infection, obesity, smoking, older age, gender (mostly reported as female), hypertension, diabetes, and use of corticosteroids [10–14].

CT scan has become a routine examination for abdominal IH, especially for huge hernia. Besides demonstrating the location, size and content of hernia, as well as helping to determine the presence of intestinal obstruction and necrosis, CT examination of the abdomen can quantitatively measure body composition, in particular visceral fat area and abdominal wall subcutaneous fat content, abdominal wall muscle and psoas muscle mass. CT measurement of body composition is quite reliable. For example, cross-sectional CT measurements of muscle and subcutaneous fat tissue are consistent with autopsy results [15]. Furthermore, fat and fat-free tissue measurement at L3 level using CT strongly correlate with whole-body fat and fat-free mass [16]. Numerous studies have delineated that visceral fat area and subcutaneous fat area measured on CT image can predict re-herniation and surgical site infection [17, 18]. Moreover, visceral obesity, rather than elevated BMI, is associated with IH after colorectal surgery [19, 20]. To date, there is very limited knowledge on the relationship between psoas CT measurement parameters and susceptibility to IH.

In this study, we recruited patients who underwent appendicectomy due to appendicitis, and divided them into two groups based on whether they had developed IH or not. We explored the relationship between psoas CT measurements and IH. After adjusting for age, gender and smoking, psoas CT attenuation was a protective factor for IH, and FIR a risk factor for IH; while PMI and sarcopenia hardly affect the occurrence of IH.

Muscles are composed of muscle fibers and intramuscular adipose tissue. Unlike erector spinae, psoas atrophy is mainly manifested by volume reduction and morphological changes, with unobvious fat deposition. Therefore, previous studies on IH had mainly focused on psoas muscle area and skeletal muscle index (SMI). However, in addition to volume reduction, muscle atrophy may pathologically exhibit fatty infiltration and muscle fibers loss [5, 6]. Some authors believe that CT attenuation may accurately reflect the number of muscle fibers and the degree of fat deposition [21]. Muscle CT attenuation is related to various diseases: paraspinal muscle density was associated with facet joint osteoarthritis, spondylolisthesis and disc narrowing at the same level [22]; lower thigh muscle CT attenuation could increase the risk of hip fracture, and a 1 SD decrease in thigh muscle HU value conferred a nearly 40% increase in the risk of hip fracture [23]; for critically ill adult patients treated with mechanical ventilation, those with a lower skeletal muscle CT value at admission had a higher 6-month mortality rate, and a 10 HU increase in muscle density was associated with a 14% decrease in hospital length of stay [25]; cancer patients with cachexia and low muscle CT values had a poor prognosis [25].

Skeletal muscle density inversely correlated with length of hospitalization after complex abdominal wall hernia surgery [26]. In our study, patients with lower psoas attenuation were more likely to develop IH. CT attenuation of abdominal wall muscles may correlate with that of psoas [27]. Decreased CT attenuation of muscle is independently associated with muscle weakness [28]. Therefore, lower CT attenuation of psoas indirectly reflects weakness of the abdominal wall muscle, which is susceptible to hernia [29].

In our study, patients with higher FIR of psoas were prone to develop IH. Fatty infiltration of skeletal muscle has been identified as a possible cause of loss of muscle quality [28]. Fatty infiltration induces insulin resistance, which impairs normal capacity for protein synthesis, subsequently contributing to muscle atrophy [30, 31]. Previous studies often applied magnetic resonance imaging (MRI) to quantitatively measure muscle fat content [32, 33], and concluded that paraspinal fat infiltration, rather than muscle CSA, was associated with high-intensity pain/disability and structural abnormalities in the lumbar spine [34]. Moreover, in patients with L4-5 single-segment degenerative lumbar spinal stenosis, fatty infiltration in the multifidus muscles at L5-S1 may be correlated with the disc bulge at the stenosis segment and reduction of lumbar lordosis [35]. Since MRI examination is not routinely performed on hernia patients, MRI-measured muscle fat content in these patients is not widely-applied. Prior literatures about CT imaging mostly used HU value to indirectly represent muscle fat content. However, since muscle CT attenuation can be affected by previous surgery and deposition of high-density substances, such as calcium and bleeding, it may not effectively reflect fat content of muscle. WC et al reported that psoas CT attenuation in patients with osteoporosis fracture was unexpectedly higher than those without osteoporosis fracture [36], which may be related to intra-muscular hemorrhage or muscle repair after fracture. In this case, CT attenuation cannot accurately reflect muscle fiber content as well as the degree of fat accumulation. Although relatively complex, measuring intramuscular fat area or muscle FIR by defining CT threshold can more accurately reflect the degree of muscle fat infiltration. When intramuscular fat area was quantitatively measured by CT, rotator cuff fat infiltration conferred functional recovery after shoulder arthroplasty [37]. To our knowledge, this is the first study to explore potential relationship between FIR and IH. We concluded that compared with CT attenuation, FIR was more closely related to IH.

Previous studies, to investigate the roles of abdominal muscles in malignancies, mostly measured muscle area of L3 or L4 cross-sectional image, including psoas, erector spinae, quadratus lumborum, transversus abdominus, rectus abdominus, as well as internal and external obliques. The corresponding SMI might predict prognosis of various malignancies [7, 38]. Based on SMI (calculated by measuring L3 level cross-section muscles), sarcopenia was not a risk factor for IH [39]; but it prolonged postoperative hospital-stay [26].

Since the measurement method mentioned above needs to be performed on a specific post-processing software by defining the range of CT values to exclude intermuscular fat, which is very labor-intensive, its application in clinical is very limited. To measure psoas area at L3 level only is simple, and corresponding PMI correlates with the whole-body muscle mass [40]. A decrease in PMI indicates a decline in whole-body muscle mass (including abdominal wall muscles), which results in decreased functional capacity. Thus, PMI may be a potential risk factor for IH. In our research, PMI at L3 level was a protective factor for IH in univariate regression analysis, but not statistically significant in multivariate regression analysis. Sarcopenia, as defined by cut-off values in previous study (based on Asians), was not associated with IH neither in univariate nor in multivariate regression analysis.

This study has several limitations. First, wound infection after surgery can be prone to IH. However, some patients did not remember clearly whether they had postoperative infection or not, since more than ten years or even decades had passed from appendectomy to this admission. Taking recall-bias into consideration, wound infection was not included in statistical analysis. Second, cross-sectional retrospective study design limits our ability to ascertain causality, and may cause selection bias inevitably. Thus, our conclusion needs to be verified by a larger sample size.

Conclusion

In summary, our study indicates that decreased CT attenuation and increased FIR of psoas are risk factors for IH after appendectomy. For patients, who have a history of abdominal surgery, with low psoas CT attenuation or high psoas FIR, prophylaxis of hernia should be conducted to reduce the occurrence of IH.

List Of Abbreviations

AUC Area under the curve

BMI Body mass index

CSA Cross-sectional area

CT Computed tomography

FIR Fatty infiltration rate

HU Hounsfield unit

IH Incisional hernia

IQR Interquartile range

MRI Magnetic resonance imaging

PMI Psoas muscle index

ROC Receiver operating characteristic

SD Standard deviation

SMI Skeletal muscle index

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of Beijing Chaoyang Hospital, Capital Medical University. Written informed consent was obtained from each participant.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

XD and PS contributed to CT measurement and paper drafting. YL participated in collecting clinical data. XG and YY were part of research design and paper drafting. ZP participated in designing research and reviewing the manuscript.

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References

1. Tanaka EY, Yoo JH, Rodrigues AJ, Utiyama EM, Birolini D, Rasslan S. A computerized tomography scan method for calculating the hernia sac and abdominal cavity volume in complex large incisional hernia with loss of domain. Hernia 2010; 14(1):63-9.
2. Huszty G, Mogami K, Sawada T et al. Preoperative evaluation of irreversible bowel ischemia in obturator hernia. Hepato-gastroenterol 2007; 54(75):775-9.
3. Angelelli G, Scardapane A, Memeo M, Stabile Ianora AA, Rotondo A. Acute bowel ischemia: CT findings. Eur J Radiol 2004; 50(1):37-47.

4. Jang M, Park HW, Huh J et al. Predictive value of sarcopenia and visceral obesity for postoperative pancreatic fistula after pancreaticoduodenectomy analyzed on clinically acquired CT and MRI. Eur Radiol 2019; 29(5):2417-25.
5. DuBay DA, Choi W, Urbanchek MG et al. Incisional Herniation Induces Decreased Abdominal Wall Compliance via Oblique Muscle Atrophy and Fibrosis. Ann Surg 2007; 245(1):140-6.
6. Amato G, Agrusa A, Romano G et al. Muscle degeneration in inguinal hernia specimens. Hernia 2012; 16(3):327-31.
7. van Vledder MG, Levolger S, Ayez N, Verhoef C, Tran TCK, IJzermans JNM. Body composition and outcome in patients undergoing resection of colorectal liver metastases. Brit J Surg 2012; 99(4):550-7.
8. Kim JS, Kim WY, Park HK, Kim MC, Jung W, Ko BS. Simple Age Specific Cutoff Value for Sarcopenia Evaluated by Computed Tomography. Ann Nutr Metab 2017; 71(3-4):157-63.
9. Bower C, Roth JS. Economics of Abdominal Wall Reconstruction. Surg Clin N Am 2013; 93(5):1241-53.
10. Walming S, Angenete E, Block M, Bock D, Gessler B, Haglind E. Retrospective review of risk factors for surgical wound dehiscence and incisional hernia. Bmc Surg 2017; 17(1):19.
11. Bewö K, Österberg J, Löfgren M, Sandblom G. Incisional hernias following open gynecological surgery: a population-based study. Arch Gynecol Obstet 2019; 299(5):1313-9.
12. Comajuncosas J, Hermoso J, Gris P et al. Risk factors for umbilical trocar site incisional hernia in laparoscopic cholecystectomy: a prospective 3-year follow-up study. Am J Surg 2019; 207(1):1-6.
13. Guitarte C, Grant J, Zhao H, Wang S, Ferriss JS, Hernandez E. Incisional hernia formation and associated risk factors on a gynecologic oncology service: an exploratory analysis. Arch Gynecol Obstet 2016; 294(4):805-11.
14. Yahchouchy-Chouillard E, Aura T, Picone O, Etienne J, Fingerhut A. Incisional hernias. I. Related risk factors. Digest Surg 2003; 20(1):3-9.
15. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol 1998; 85(1):115-22.
16. Mourtzakis M, Prado CMM, Lieffers JR, Reiman T, McCargar LJ, Baracos VE. A practical and precise approach to quantification of body composition in cancer patients using computed tomography images acquired during routine care. Appl Physiol Nutr Me 2008; 33(5):997-1006.
17. Winters H, Knaapen L, Buyne OR et al. Pre-operative CT scan measurements for predicting complications in patients undergoing complex ventral hernia repair using the component separation technique. Hernia 2019; 23(2):347-54.
18. Yamada T, Okabayashi K, Hasegawa H et al. Age, Preoperative Subcutaneous Fat Area, and Open Laparotomy are Risk Factors for Incisional Hernia following Colorectal Cancer Surgery. Ann Surg Oncol 2016; 23 Suppl 2:S236-41.

19. Yamamoto M, Takakura Y, Ikeda S, Itamoto T, Urushihara T, Egi H. Visceral obesity is a significant risk factor for incisional hernia after laparoscopic colorectal surgery: A single-center review. Asian J Endosc Surg 2018; 11(4):373-7.
20. Aquina CT, Rickles AS, Probst CP et al. Visceral Obesity, Not Elevated BMI, Is Strongly Associated with Incisional Hernia After Colorectal Surgery. Dis Colon Rectum 2015; 58(2):220-7.
21. Goodpaster BH, Kelley DE, Thaete FL, He J, Ross R. Skeletal muscle attenuation determined by computed tomography is associated with skeletal muscle lipid content. J Appl Physiol 2000; 89(1):104-10.
22. Kalichman L, Hodges P, Li L, Guermazi A, Hunter DJ. Changes in paraspinal muscles and their association with low back pain and spinal degeneration: CT study. Eur Spine J 2010; 19(7):1136-44.
23. Lang T, Cauley JA, Tylavsky F, Bauer D, Cummings S, Harris TB. Computed tomographic measurements of thigh muscle cross-sectional area and attenuation coefficient predict hip fracture: The health, aging, and body composition study. J Bone Miner Res 2010; 25(3):513-9.
24. Looijaard WGPM, Dekker IM, Stapel SN et al. Skeletal muscle quality as assessed by CT-derived skeletal muscle density is associated with 6-month mortality in mechanically ventilated critically ill patients. Crit Care 2016; 20(1):386.
25. Martin L, Birdsell L, MacDonald N et al. Cancer Cachexia in the Age of Obesity: Skeletal Muscle Depletion Is a Powerful Prognostic Factor, Independent of Body Mass Index. J Clin Oncol 2013; 31(12):1539-47.
26. Rinaldi JM, Geletzke AK, Phillips BE, Miller J, Dykes TM, Soybel DI. Sarcopenia and sarcopenic obesity in patients with complex abdominal wall hernias. Am J Surg 2016; 212(5):903-11.
27. Sebro R, O Brien L, Torriani M, Bredella MA. Assessment of trunk muscle density using CT and its association with degenerative disc and facet joint disease of the lumbar spine. Skeletal Radiol 2016; 45(9):1221-26.
28. Goodpaster BH, Carlson CL, Visser M et al. Attenuation of skeletal muscle and strength in the elderly: The Health ABC Study. J Appl Physiol 2001; 90(6):2157-65.
29. Jensen KK, Kjaer M, Jorgensen LN. Isometric abdominal wall muscle strength assessment in individuals with incisional hernia: a prospective reliability study. Hernia 2016; 20(6):831-7.
30. Rivas DA, McDonald DJ, Rice NP, Haran PH, Dolnikowski GG, Fielding RA. Diminished anabolic signaling response to insulin induced by intramuscular lipid accumulation is associated with inflammation in aging but not obesity. Am J Physiol Reg I 2016; 310(7):R561-9.
31. Hamrick MW, McGee-Lawrence ME, Frechette DM. Fatty Infiltration of Skeletal Muscle: Mechanisms and Comparisons with Bone Marrow Adiposity. Front Endocrinol 2016; 7:69.
32. Alizai H, Nardo L, Karampinos DC et al. Comparison of clinical semi-quantitative assessment of muscle fat infiltration with quantitative assessment using chemical shift-based water/fat separation in MR studies of the calf of post-menopausal women. Eur Radiol 2012; 22(7):1592-600.
33. Morrow JM, Sinclair CDJ, Fischmann A et al. Reproducibility, and age, body-weight and gender dependency of candidate skeletal muscle MRI outcome measures in healthy volunteers. Eur Radiol

2014; 24(7):1610-20.

34. Teichtahl AJ, Urquhart DM, Wang Y et al. Fat infiltration of paraspinal muscles is associated with low back pain, disability, and structural abnormalities in community-based adults. Spine J 2015; 15(7):1593-601.
35. Liu Y, Liu Y, Hai Y, Li G, Liu T, Wang Y. Lumbar lordosis reduction and disc bulge may correlate with multifidus muscle fatty infiltration in patients with single-segment degenerative lumbar spinal stenosis. Clin Neurol Neurosur 2020; 189:105629.
36. Wang C, Hou X, Zhang Y, Wang L, Cheng XG. Change of the psoas major in postmenopausal spinal osteoporotic fractures: a computed tomography. Chin J Bone Jt 2016; 5(8):577-81.
37. Lapner PLC, Jiang L, Zhang T, Athwal GS. Rotator Cuff Fatty Infiltration and Atrophy Are Associated with Functional Outcomes in Anatomic Shoulder Arthroplasty. Clin Orthop Relat R 2015; 473(2):674-82.
38. Lieffers JR, Bathe OF, Fassbender K, Winget M, Baracos VE. Sarcopenia is associated with postoperative infection and delayed recovery from colorectal cancer resection surgery. Brit J Cancer 2012; 107(6):931-6.
39. van Rooijen MMJ, Kroese LF, van Vugt JLA, Lange JF. Sarcomania? The Inapplicability of Sarcopenia Measurement in Predicting Incisional Hernia Development. World J Surg 2019; 43(3):772-9.
40. Hamaguchi Y, Kaido T, Okumura S et al. Proposal for new diagnostic criteria for low skeletal muscle mass based on computed tomography imaging in Asian adults. Nutrition 2016; 32(11-12):1200-5.

Figures

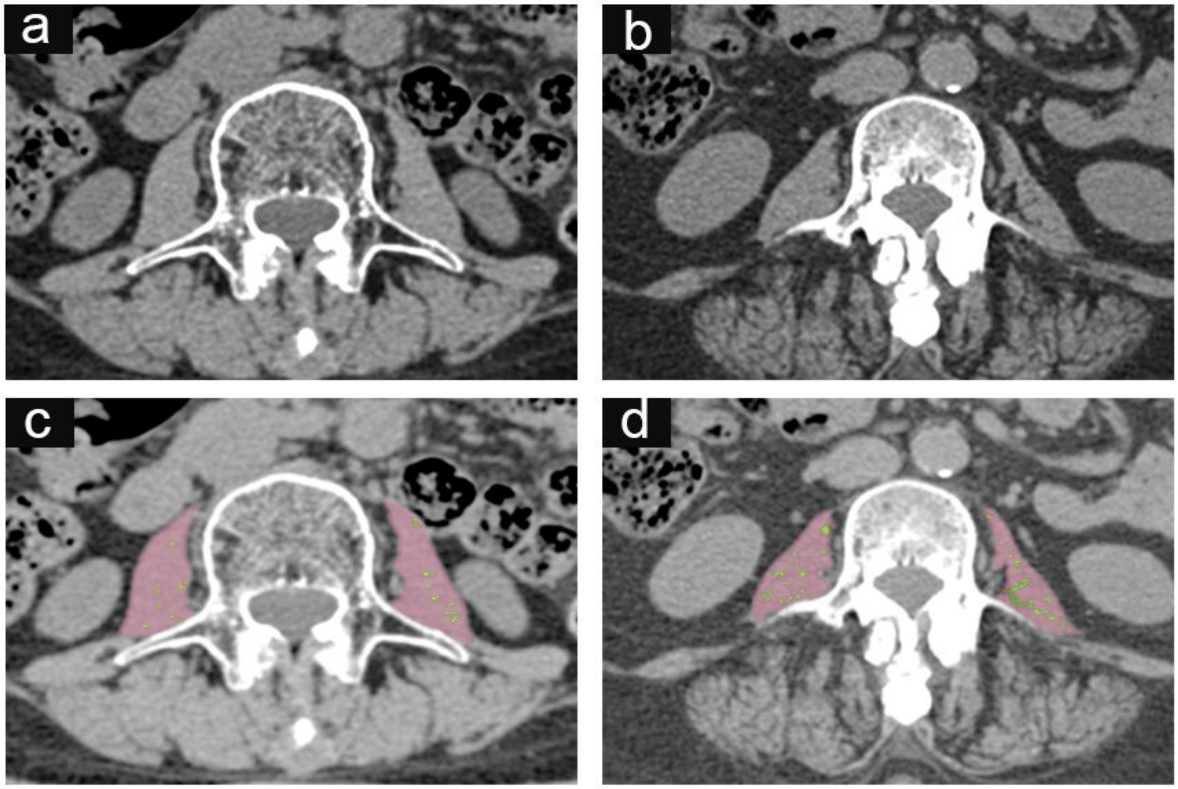

Figure 1

Measurement of psoas. Images a and c from a non-IH patient (64 year-old, Female) display a higher CT attenuation (47 HU) and a lower FIR (green, 2.1%); images b and d from an IH patient (67 year-old, Female) exhibit a lower CT attenuation (24 HU) and a higher FIR (green, 9.4 %). Their PMIs are roughly equal (4.0 cm2/m2 vs. 4.1 cm2/m2).

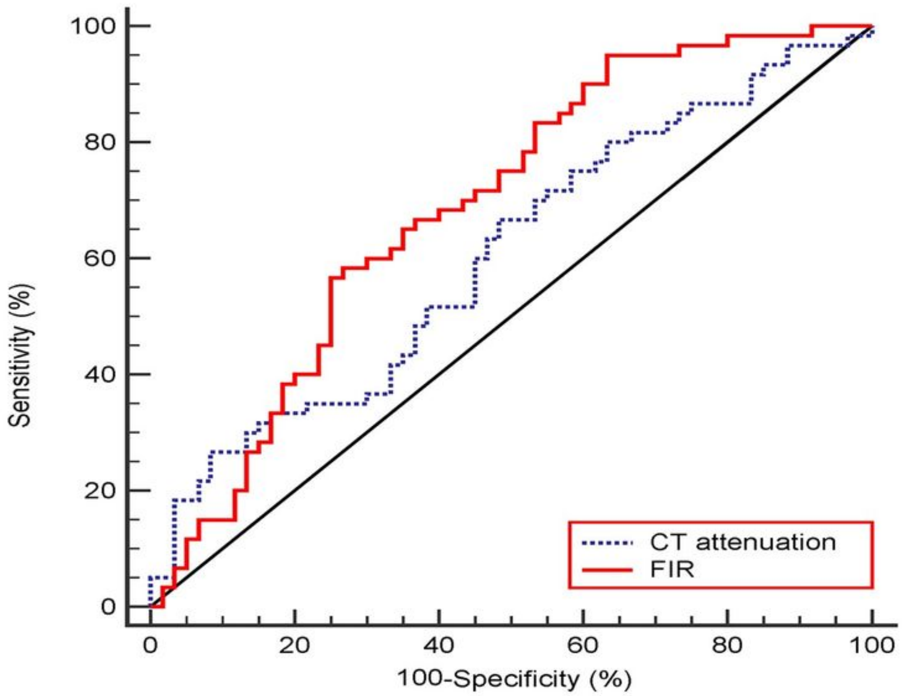

Figure 2

The ROC curve of CT attenuation and FIR. FIR has a higher diagnostic value than CT attenuation. The AUC of FIR for diagnosing IH is 0.689 (95% CI 0.60-0.77), with a cutoff at 3.8%, sensitivity of 58.33%, and specificity of 73.3%. The AUC of CT attenuation for diagnosing IH is 0.604 (95% CI 0.51-0.69), with a cutoff at 43.5 HU, sensitivity of 66.67% and specificity of 51.67%.