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Evaluation of individual and composite CT-based markers in frailty diagnostics in older patients with cancer undergoing major abdominal surgery

Jerzy Krzeszowiak[1*], Szymon Wróbel[2], Alicia del Carmen Yika[2], Wojciech Rudnicki[3] and Jakub Kenig[4*]

Abstract

Background Frailty, a multifactorial syndrome associated with age-related decline in physiological reserves, is a critical determinant of surgical outcomes in the elderly. Comprehensive Geriatric Assessment (CGA) is the gold standard for diagnosing frailty but is resource-intensive. This study investigates the relationship between CT parameters and frailty syndrome based on CGA. Additionally, it aims to evaluate the effectiveness of the proposed composite radiological score in diagnosing frailty and predicting postoperative complications.

Methods The study was a retrospective analysis of prospectively collected data. Patients ≥ 65, undergoing major abdominal oncologic surgery between January 2022 and August 2023, with available CT scans and preoperative CGA were enrolled. The radiological parameters analyzed included sarcopenia, osteoporosis, renal atrophy, abdominal aorta calcification (AAC) and sarcopenic obesity. These parameters were analyzed both individually and as a composite score in relation to frailty syndrome.

Results A total of 79 patients were included in the study. The median age of included patients was 73 (IQR 68–76). Frailty was diagnosed in 50.63% of the group, with colorectal cancer (37.97%) being the most common indication for surgery. AAC and psoas muscle radiodensity was significantly higher in frail patients, while there were no significant differences in other radiological parameters. The AUROC of the radiological composite frailty score for detecting moderate or severe frailty was 0.686 ($p = 0.008$).

Conclusions This study demonstrates that AAC could be considered as a significantly useful radiological marker of frailty, while other individual radiological parameters are insufficient for frailty diagnosis. Moreover, radiological composite frailty score is a promising tool for diagnosing severe frailty.

Keywords Frailty syndrome, Oncologic surgery, Computed tomography, Older patients, Radiological markers

*Correspondence:
Jerzy Krzeszowiak
jerzy.krzeszowiak@uj.edu.pl
Jakub Kenig
jakub.kenig@uj.edu.pl
[1]Department of Medical Education, Jagiellonian University Medical College, Medyczna 7, 30-688, Krakow, Poland
[2]Jagiellonian University Medical College, Sw. Anny 12, 31-008, Krakow, Poland
[3]Department of Electroradiology, Jagiellonian University Medical College, Krakow, Poland
[4]Department of General, Gastrointestinal, Oncologic Surgery and Transplantology, I Chair of General Surgery Jagiellonian University Medical College, 2 Jakubowskiego str. 30-688, Krakow, Poland

Introduction

Frailty is a multifactorial, progressive syndrome that decreases the ability to withstand outside stressors, and it is representative of biological age [1–3]. Although frailty is often associated with aging, it can also occur in younger individuals and is not solely determined by chronological age. The aging population means progressively older patients undergo surgical treatment and determining frailty becomes a priority for adequate medical care [4]. The most thorough way to evaluate frailty is by applying Comprehensive Geriatric Assessment (CGA) [5–7] which allows for quantitative value of frailty. It consists of general domains concerning physical health, cognitive health, mood, functioning, comorbidities risk, polypharmacy, and socioeconomic circumstance [8]. The main drawback of the CGA is it's time-consuming and resource-demanding (although the additional 30–40 min during preoperative assessment seems to be a low price to pay for the possibility to improve short- and long-term outcomes) hence the need for developing frailty screening tests appropriate for patients undergoing surgical treatment.

Abdominal computed tomography scan provides multitude of information about body composition and signs of diseases associated with ageing. Frailty examination using CT scans would allow objective and quantifiable frailty screening. CT scans are routinely conducted on surgical patients, eliminating the necessity for additional patient participation. Contrary to CGA and physical tests it can be done to patients in serious condition and without full medical history [9]. Previous studies in this area examined CT markers in correlation with discharge disposition, 30-day mortality or simplified frailty examination whereas we set a full CGA done prospectively as frailty determining factor [10–12]. Although individual markers have not yet proven to be an adequate approximation of frailty there is a chance for composite scores to be a better screening tool [10].

In the present study, we aim to investigate the relationship between frailty diagnosed using CGA and CT markers of atherosclerosis, sarcopenia, sarcopenic obesity, osteopenia, and renal atrophy. These markers were chosen based on their hypothesised predictive value in previous studies [10–14]. In general screening populations aorta calcification is an established predictor of cardiovascular incidents and overall mortality. Therefore, it is also hypothesized to be of value in surgical patients [9] and proved to be correlated with worse postoperative outcomes [15–19]. Psoas muscle cross section area measurement is a proven method of sarcopenia detection which is a generalised and progressive skeletal muscle disorder linked with increased likelihood of adverse outcomes that include falls, fractures, physical disability, mortality, and poorer postoperative outcomes [14, 20, 21]. Additionally, there is a significant overlap between sarcopenia and frailty as shown by Fried et al. [22]. Sarcopenic obesity seems to be an independent prognostic factor for mortality [9], prevalent in the geriatric population. Osteopenia is characterised by decreased bone mineral density, and it is an important predictor of all-cause mortality and complications in oncologic patients [9]. Renal volume is known to decrease with age and can reach up to 40% loss of cortical mass in 80-years-old patients [23]. Therefore, it may be a good representation of biological age.

The primary aim of the study was to investigate the relationship between individual CT parameters and frailty syndrome based on CGA. Moreover, the study aimed to check the effectiveness of the proposed composite radiological score in diagnosing of frailty. The secondary objective was to assess the efficacy of radiological composite score in prediction of postoperative complications.

Materials and methods

The study was a retrospective analysis of prospectively collected data. It has been approved by the Bioethics Committee of Jagiellonian University (number of approval: 1072.6120.125.2020).

Consecutive patients operated in the University Hospital in Krakow, Poland, between January 2022 and August 2023 were enrolled. The inclusion criteria were age ≥ 65 years, CT scans available in the hospital system and performed within 6 months preoperatively, elective major, oncologic abdominal surgery performed during the hospitalization. Types of surgery qualifying for inclusion comprised: colorectal procedures (left and right hemicolectomies, anterior rectal resections, abdominal-perineal resections), gastric and esophageal procedures (total and partial gastrectomies, partial esophageal resection), liver surgeries (right hemihepatectomies, non-anatomical bisegmentectomies), pancreatic procedures (pancreatoduodenectomies, distal and total pancreatectomies), palliative procedures (colostomies, gastrointestinal bypass procedures due to gastric or pancreatic tumors) other oncological surgeries (adrenalectomies, cytoreductive surgery with hyperthermic intraperitoneal chemotherapy, inguinal lymphadenectomies). Both open (laparotomy) and laparoscopic approaches were included.

Comprehensive geriatric assessment

The CGA were applied to all patients up to one week to hospital admission (in most cases, on the day of admission) by the trained staff of the geriatric team, based on uniform protocol. It consisted of 10 validated scales or tests, representative of 8 domains (functional, physical, comorbidity, emotional, cognitive, nutritional, polypharmacy, and social support), which are proved to best define frailty syndrome. Impairment of >3 domains allowed to diagnose frailty syndrome. Patients with ≤ 3 domains impaired were defined as fit. Severity of frailty was defined as the number of the domains which were impaired on a 1–8 scale (Table 1) [6]. Patients with impairment of 4 domains were classified as having minor frailty, those with impairment in 5 or 6 domains as having moderate frailty, and those with impairment in 7–8 domains as severe frailty syndrome.

The Functional Domain was assessed using the ADL and iADL scales. The results ≤ 5/6 or < 7/8, respectively were considered indicative of domain impairment [24, 25]. The Physical Domain was evaluated using 4-meter Test, in which patient walks 6 m (1 m of acceleration, 4 m of test and 1 m of deceleration), while the researcher measures the time (middle 4 m). A time the >5s was considered as the impairment of the domain [26]. In 3 patients, the 5 Chair Stand Test was used instead of the 4-meter Test. In this test patient stands up from a chair and sits down 5 times without using their hands. The impairment cut-off point for this test was >15s [27].The use of the 5 Chair Stand Test was caused by patients' medical condition or their lack of compliance with the 4-meter Walk Test. For the Comorbidity Domain, Charlson Comorbidity Index was applied, with the impairment cut-off point of 5 points, corresponding to an estimated 21% of 10-year survival [28]. Geriatric Depression Scale was used for the Emotional Domain screening [29], while Nutritional Domain was evaluated with Nutritional Risk Screening tool [30]. The Cognitive Domain assessment was performed using Blessed Orientation-Memory-Concentration Test and Clock Drawing Test. Scores >10/28 points or >3/7 in either test, respectively, were considered as the impairment of Cognitive Domain [31, 32]. Polypharmacy was defined as the regular intake of >7 medications [33, 34]. The Social Support Domain was evaluated with Medical Outcomes Study Social Support Survey, with the impairment cut-off point set at < Q1 of the results within our group [35] (Table 1).

Computed tomography measurements

CT scans of enrolled patients were evaluated using Siemens Healthineers software. For the purpose of image analysis, non-contrast CT scans were used, as CT imaging is routinely performed preoperatively in the majority of oncological patients undergoing surgery. Non-contrast abdominal scans have been shown to provide greater reliability for the assessment of arterial calcification [36]. Factors that have been assessed on CT scans included: psoas muscles, L3 vertebrae, kidneys, abdominal aorta calcification, quantity of abdominal fat and muscle tissue. CT scans were assessed by radiologists and medical students who had received prior training from the radiologists. All researchers were blinded to the patients' frailty status and clinical course.

Table 1 Description of comprehensive geriatric assessment protocol

Comprehensive Geriatric Assessment [6]		
Test/Tool:	**Items/scale:**	**Impairment cut-off point:**
Functional Domain [24, 25]:		
*ADL	6 items	≤ 5/6 or
**iADL	8 items	< 7/8
Physical Domain [26]:		
4 m Test	Patient walks 6 m (1 m of acceleration, 4 m of test and 1 m of deceleration). Researcher measures time.	> 5s
Comorbidity Domain [28]:		
Charlson Comordibity Index	-max 37 points -the higher result the lower estimated 10-year survival	> 5 points *5 points = 21% of 10 year estimated survival
Emotional Domain [29]:		
Geriatric Depression Scale	4 items	< 4
Nutritional Domain [30]:		
Nutritional Risk Screening	3 items	> 0
Cognitive Domain [31, 32]:		
***BOMC Test	6 items 0-28 points	> 10/28 or
Clock Drawing Test	0–7 points	> 3/7
Polypharmacy Domain [33]:		
Number of drugs taken		> 7
Social Support Domain [35]:		
****MOS Social Support Survey	5 items	< Q1 of our group

Number of impaired domains > 3 = Frailty Syndrome

Sarcopenia
Major psoas muscles area and mean radiodensity were measured using manual tracing on the cross-sectional scan at level of the L3 vertebra [10, 11, 37]. The area of both muscles was summed to obtain total psoas area (TPA) and was standardized for patients' height.

Osteoporosis
The vertebra was measured at the level of L3 using manual tracing. Data about the area standardized for height and mean radiodensity were collected [10, 13].

Renal atrophy
For renal atrophy analysis kidneys volume was measured, using the semi-automatic tracing method. Both kidneys volume and mean radiodensity have been evaluated [10, 11].

Abdominal aorta calcification
Abdominal aorta calcification was evaluated using three methods, including two quantitative measurements based on the software tools and a subjective researcher assessment of the intensity of the calcification. Measurement methods have been inspired by the Agatston formula [38], which defines each lesion within aorta >1mm^2, with radiodensity ≥ 130 HU a calcification.

The first measurement method used a semiautomatic tracing tool, based on marking cross-sections of aorta circumference beginning from celiac trunk origin up to the bifurcation of aorta, and creating *manually measured aorta segment* (MMAS). The second measurement method included the segment of the aorta identified automatically by the software (AMAS – automatically measured aorta segment. In both methods segments' volume and radiodensity were analyzed. By using the threshold of 130 HU we identified all calcification plaques within the aorta segment and collected information about their volume and radiodensity. Additionally, we calculated the ratio of calcification volume/aorta segment volume [11].

The subjective analysis included calcification intensity evaluation using a 0–10 visual scale (ACVS – aorta calcification visual scale) [39]. Moreover, we calculated the number of the visible calcification plaques within the segment of the aorta reaching from the origin of the celiac trunk until the aorta bifurcation (ACCV – number of aortic calcifications calculated visually) [40].

Sarcopenic obesity
Sarcopenic obesity based on the amount of abdominal fat and muscle tissue, was analyzed using automatic software modalities on the level of L3 vertebra. We analyzed area and radiodensity of both tissues and the fat tissue/muscle tissue ratio [10, 41].

Radiological composite frailty score Based on the analyzed radiological parameters we proposed Radiological Composite Frailty Score (RCFS) consisting of five components: TPA, body of L3 vertebra HU, volume of kidneys, abdominal aorta calcification (mean radiodensity of aorta segment) and abdominal fat tissue/muscle tissue ratio. The impairment of each component was either defined using cutoff points from the previous studies or calculated using IQR (Table 2). The RCFS was expressed on a 0–5 scale. The impairment of each component was calculated as one point.

Clinical data
Additional patients' clinical data such as diagnosis, type of operation, postoperative complications (Clavien and Dindo Classification [42], Comprehensive Complication Index [43]), length of stay, ICU admissions, 30-day postoperative mortality were collected. Major complications were defined as Dindo-Clavien Classification ≥ 3.

Statistical analysis
Statistical analysis was performed using IBM SPSS Statistics version 29.0.0.0 (241). Data distribution analysis using Shapiro-Wilk test was performed for all groups and revealed abnormal distribution, so non-parametric tests were used. For comparisons of quantitative variables, the U-Mann-Whitney test was used, and for the nominative the Chi^2 test. The correlations were calculated using Spearman correlation. The ROC curve was created and

Table 2 – Description of radiological composite frailty score domains

Radiological Composite Frailty Score 0–5 points		
Component	**Measured parameter**	**Cut-off point for impairment**
Sarcopenia [10, 11, 37]	The area of both major psoas muscles (TPA) on the level of L3 vertebra, normalized for height	≤ 5.21 cm2/m2 [10]
Osteoporosis [10, 13]	The radiodensity of the body of L3 vertebra	< 110 HU [13]
Renal atrophy [10, 11]	The volume of both kidneys, normalized for height.	< Q1 (< 96.91 cm3/m2)
Abdominal aorta calcification [38–40]	The mean radiodensity of the segment of aorta from the origin of celiac trunk up to the aorta bifurcation.	>Q3 (> 50 HU)
Sarcopenic obesity [10, 41]	The ratio of abdominal fat tissue/muscle tissue on the level of L3.	>Q3 (> 1.23)

Impairment of each component = 1 point

Table 3 – Characteristics of enrolled group

		n or median	% or IQR
Number of patients		79	100.00%
Sex	M	27	34.18%
	F	52	65.82%
Age [years]		73	68–76
Age groups	< 75	53	67.09%
	≥ 75	26	32.91%
Type of operation:	colorectal	30	37.97%
	right hemicolectomies	13	16.46%
	left hemicolectomies	4	5.06%
	anterior rectal resections	11	13.92%
	abdominal-perineal resections	2	2.53%
	gastric and oesophageal	14	17.72%
	total gastrectomies	8	10.12%
	partial gastrectomies	5	6.33%
	partial esophageal resections	1	1.27%
	pancreatic	11	13.92%
	pancreatoduodenectomies	5	6.33%
	distal pancreatectomies	5	6.33%
	total pancreatectomies	1	1.27%
	liver	8	10.13%
	right hemihepatectomies	3	3.80%
	non-anatomical bisegmentectomies	5	6.33%
	palliative procedures	10	12.66%
	gastrointestinal bypass	7	8.86%
	colostomies	3	3.80%
	other oncological	6	7.59%
	cytoreductive surgery with hyperthermic intraperitoneal chemotherapy	4	5.06%
	Inguinal lymphadenectomy	1	1.27%
	adrenalectomy	1	1.27%
Surgical approach	laparotomy	65	82.28%
	laparoscopy	14	17.72%
Frailty syndrome	yes	40	50.63%
	no	39	49.37%
	depth (0–8) in frail patients	4	2–5
Time from CT to CGA	days	47	23.5–84
Postoperative complications	yes	51	64.56%
	no	28	35.44%
Clavien-Dindo Classification	I	13	16.46%
	II	28	35.44%
	III	4	5.06%
	IV	4	5.06%
	V	2	2.53%

analyzed to evaluate the efficacy of RCFS in detection of frailty syndrome and postoperative complications.

Results

Group characteristics

79 consecutive patients who underwent major oncologic surgery, had a CGA prior to the operation and had CTs available in the hospital database, were included in the study. The majority of the group were female (65.82%) with a median age of 73 (IQR 68–76). The characteristics of the study population are presented in Table 2. According to CGA, frailty syndrome was diagnosed in 50.63% of patients. The median frailty depth in frail patients was 4 (IQR 2–5) (Table 3).

CGA results

The prevalence of frailty syndrome was greater in the group ≥ 75 than in the younger group (80.77% vs. 35.85%; $p < 0.001$) and the median depth of frailty was also significantly higher in the older group (4 vs. 3; $p < 0.001$). Nevertheless, taking a closer look, the differences in the prevalence of the domain impairment between older and younger groups were significant only in three out of eight domains: functional (42.31% vs. 18.87%; $p = 0.028$), polypharmacy (42.31% vs. 16.98%; $p = 0.016$) and cognitive (76.92% vs. 39.62%; $p = 0.002$), while remaining five (physical, comorbidity, nutritional, social support and emotional) did not differ significantly in terms of groups < 75 and ≥ 75 years old.

Comparing the CGA results between males and females the prevalence of frailty syndrome was similar in both groups and there were not any significant differences in CGA domains.

CT measurement results vs. frailty

Analyzed morphological parameters of the abdomen CT scans were compared between fit and frailty of different severity groups. Comparing fit and frail group dichotomously, there were no significant differences in psoas muscle area, body of L3 vertebra radiodensity and area, kidneys volume and radiodensity and fat tissue/muscle tissue ratio. Some of the parameters of AAC were significantly higher in frail group: ACVS (6 vs. 3; $p = 0.002$), ACCV (11 vs. 7; $p = 0.005$) and MMAS radiodensity (46 HU vs. 39 HU; $p = 0.016$), while there were no significant differences in calcification volume or calcification/aorta volume. Psoas muscles radiodensity was significantly higher in fit patients (Table 4).

The radiological results of fit patients were then compared also with different stages of frailty syndrome: minor ($n = 21$), moderate ($n = 15$), and severe ($n = 4$). The analysis revealed again significantly greater burden of AAC: ACVS (7 vs. 3; $p = 0.002$), ACCV (11 vs. 7; $p = 0.005$), and MMAS radiodensity (47 vs. 39; $p = 0.023$)

in patients with minor frailty than in fit group and higher psoas muscle radiodensity (36 vs. 30; $p = 0.019$) in fit patients. There were no significant differences in any of analyzed radiological parameters between fit and moderate of severely frail patients (Table 4).

We identified the subgroups of patients with frailty who had physical ($n = 15$) or cognitive ($n = 32$) domains impairment. There were no significant differences in any of radiological parameters between groups of fit patients and these with physical frailty. The only significant differences between fit and cognitive frailty groups referred to higher ACVS (6 vs. 3; $p = 0.010$) and ACCV (11 vs. 7; $p = 0.016$) in frail patients.

Using both uni- and multivariate logistic regression models we analyzed the impact of the radiological parameters on the diagnosis of frailty syndrome. In univariate analysis, we identified three factors increasing the probability of the frailty syndrome: ACVS (OR = 1.277; CI: 1.090–1.497; $p = 0.002$), ACCV (OR 1.114; CI: 1.020–1.216; $p = 0.016$) and the radiodensity of MMAS (OR = 1.031; CI: 1.006–1.056; $p = 0.015$), all related to AAC. In the multivariate logistic regression model analysis, we included five radiological parameters, which were also considered in RCFS: TPA/height, radiodensity of the body of L3 vertebra, volume of kidneys/height, radiodensity of MMAS, and fat tissue/muscle tissue ratio. The only significant factor in multivariate analysis was the radiodensity of MMAS (OR = 1.030; CI: 1.004–1.057; $p = 0.022$).

CT measurement results vs. postoperative outcomes

CT measurements results of patients with and without postoperative complications were compared. The only significant differences referred to the higher ACCV in patients with complications (10 vs. 7.5; $p = 0.042$), lower psoas muscle radiodensity (32 vs. 38; $p = 0.023$) and lower

Table 4 Comparison of radiological measurement results between a group of fit patients and patients with frailty syndrome of different severity

		fit	frail	*p* fit vs. frailty	minor frailty	*p* fit vs. minor frailty	moderate frailty	*p* fit vs. moderate frailty	severe frailty	*p* fit vs. severe frailty
ACVS	median	3	6	**0.002**	7	**0.002**	5	0.061	5	0.207
scale (0–10)	IQR	1–7	3.25-8		4-8.50		2–8		1.5–8.50	
ACCV	median	7	11	**0.005**	11	**0.005**	10	0.080	8	0.660
number	IQR	3–11	8.25-13		9-14.50		6–13		4.75–11.25	
MMAS radiodensity	median	39	46	**0.016**	47	**0.023**	46	0.186	45	0.209
HU	IQR	32–47	35.75–74.50		38–73		34–81		36.75–77.25	
calcifications volume	median	0.17	0.55	0.110	0.52	0.086	0.59	0.414	0.42	0.687
cm3	IQR	0.065–1.39	0.22–1.60		0.29–1.60		0.18–1.80		-	
calcifications volume/ AMAS volume	median	0.0082	0.0206	0.121	0.0243	0.086	0.0205	0.399	0.0232	0.936
ratio	IQR	0.0025–0.0391	0.0065–0.0665		0.0086–0.0679		0.0055–0.0746		-	
TPA/height	median	5.05	4.5	0.444	5.44	0.648	4.23	0.071	4.26	0.558
cm2/m2	IQR	3.85–6.05	3.78–5.91		3.94–6.30		3.76–4.59		3.71–6.22	
mean TP radiodensity	median	36	32	**0.038**	30	0.019	30	0.216	35	0.851
HU	IQR	29–43	25–38		25–38		23–42		32.25–45.25	
L3 vertebra area/height	median	5.18	5	0.724	5.16	0.944	4.79	0.235	5.25	0.380
cm2/m2	IQR	4.66–5.52	4.60–5.67		4.58–5.81		4.50–5.34		5.11–6.12	
L3 vertebra radiodensity	median	151	160	0.402	151	0.698	175	0.423	166.5	0.427
HU	IQR	124–184	133.75–196		132–194		132–210		150.25–186.50	
summed volume of kidneys/height	median	107.38	112.45	0.624	118.15	0.268	103.09	0.518	123.85	0.616
cm3/m2	IQR	93.41-129.34	94.56-134.05		100.51–140.10		93.37-128.01		94.28-139.18	
mean kidney radiodensity	median	20	20	0.666	19	0.506	21.50	0.791	16.50	0.567
HU	IQR	16.50–23.50	13–24		14–23		13.75–24.75		10.50-26.25	
muscle/fat tissue ratio at L3 level	median	0.7645	0.9541	0.057	0.9183	0.147	1.212	0.120	1.3654	0.420
ratio	IQR	0.6289–1.0676	0.7257–1.7764		0.7224–1.5070		0.7257–1.8333		-	

kidney radiodensity (HU 19 vs. 20; $p = 0.049$) in patients with postoperative complications. None of the other radiological parameters differed significantly between this groups.

Multitude of methods of AAC measurement

Due to the various used methods of AAC evaluation, their correlations with frailty syndrome and postoperative morbidity were investigated. Both visual methods of AAC evaluation were significantly correlated with the depth of frailty (ACVS: $R = 0.300$, $p = 0.007$; ACCV: $R = 0.295$, $p = 0.008$) and CCI (ACVS: $R = 0.231$, $p = 0.041$; ACCV $R = 0.294$, $p = 0.009$), though the correlations were weak. The presence of frailty syndrome was also weakly correlated with ACCV ($R = 0.315$; $p = 0.005$) and MMAS radiodensity ($R = 0.272$; $p = 0.015$). The volume of calcifications both as an absolute value or with regard to the aorta segment volume did not correlate with either frailty syndrome or postoperative complications.

Radiological composite frailty score

The efficacy of radiological parameters in frailty prediction was tested using ROC analysis. The analysis of radiological parameters separately indicated that only the AUROC for AAC was statistically significant for frailty detection (AUROC = 0.0654, CI: 0.533–0.755; $p = 0.013$). ROC curves were also created to evaluate the efficacy of RCFS in detecting frailty. The results for the presence of frailty syndrome were not significant. However, when analyzed for moderate or severe frailty the AUROC proved to be significant (AUROC = 0.686; CI: 0.548–0.824; $p = 0.008$).

Additionally, ROC analysis was performed for postoperative complications, but the AUROC was insignificant for both all the individual parameters and RCFS (Fig. 1).

Discussion

Frailty is a multifactorial syndrome characterized by a decline in functioning across multiple organ systems, involving interaction between physical, psychological, cognitive, and social domains [2, 44–49]. It is associated with increased mortality, morbidity, hospitalization, institutionalization, postoperative complications, falls as well as overall functional decline and associated with it impaired quality of life [45, 49, 50]. Due to the aging population, the prevalence of frailty is expected to rise globally and soon it will be one of the major burdens for clinical practitioners. Although it is believed that it affects millions of older adults worldwide, the real prevalence is still unknown [49]. Some of the reasons include a lack of clear and universal frailty definition, scarcity of frailty diagnoses in everyday clinical practice, research done mainly in high-income countries as well a lack of definite diagnostic tools to identify frail patients. Thus, the prevalence is probably much higher [44, 45, 49]. Even despite that, the number of frail patients within our cohort was relatively high, but it could be justified by the fact that our hospital is a high-volume, tertiary care center, with predominant high risk and challenging cases.

Because of its risk factors and adverse effects, several screening tools for frailty have been introduced, among which, the Comprehensive Geriatric Assessment (CGA) is believed to be the best predictor of frailty [5, 6, 44, 45, 47, 51–53]. Furthermore, it is not a surprise that older patients can be extremely heterogenous in terms of health condition as well as their functional and socioeconomic status and that chronological age is just a number, and the one which matter is the biological one [6, 44, 51, 53].

Despite high-quality evidence, even nowadays some elderly patients are denied surgery and treated suboptimal only because of their chronological age [54, 55]. Frailty syndrome is commonly known to be a risk factor of poorer postoperative outcomes and is associated with increased mortality, morbidity, and hospital stay. Therefore, its proper diagnosis plays a crucial role in comprehensive and tailored care of elderly, surgical patients [56, 57].

Notwithstanding being a gold standard of frailty syndrome diagnosis CGA is connected with several limitations. One of the most significant is the potential for both patient- and physician-related bias within this method, such as biases related to personal communication skills, which play a crucial role in the precision of CGA performance [58]. In contrast to CGA, the evaluation of CT scans is more replicable, and with respect to quantitatively measurable parameters, the risk of personal bias is lower. Additionally, CT scans are routinely conducted in surgical patients, for whom performing a full CGA is not always feasible due to their medical and/or mental condition.

Factors such as: sarcopenia, osteopenia, renal atrophy, sarcopenic obesity, and abdominal aorta calcification are known to be processes ongoing with ageing and could be analyzed in abdominal CT scans, but in this study, we aimed to investigate whether they were also correlated with the occurrence of frailty syndrome and postoperative complications [2, 59–61].

Comparison of the radiological measurements between fit and frail group indicated that the most important differences were related to AAC. Both visual and measurable scales showed a significantly greater burden of AAC in the frail group. The mean radiodensity of the psoas muscles was also significantly lower in the frail group.

The frail group was divided into subgroups based on the stage of frailty (minor, moderate and severe). Comparing the minor frailty group to fit group, the only differences observed were in AAC and psoas muscles radiodensity.

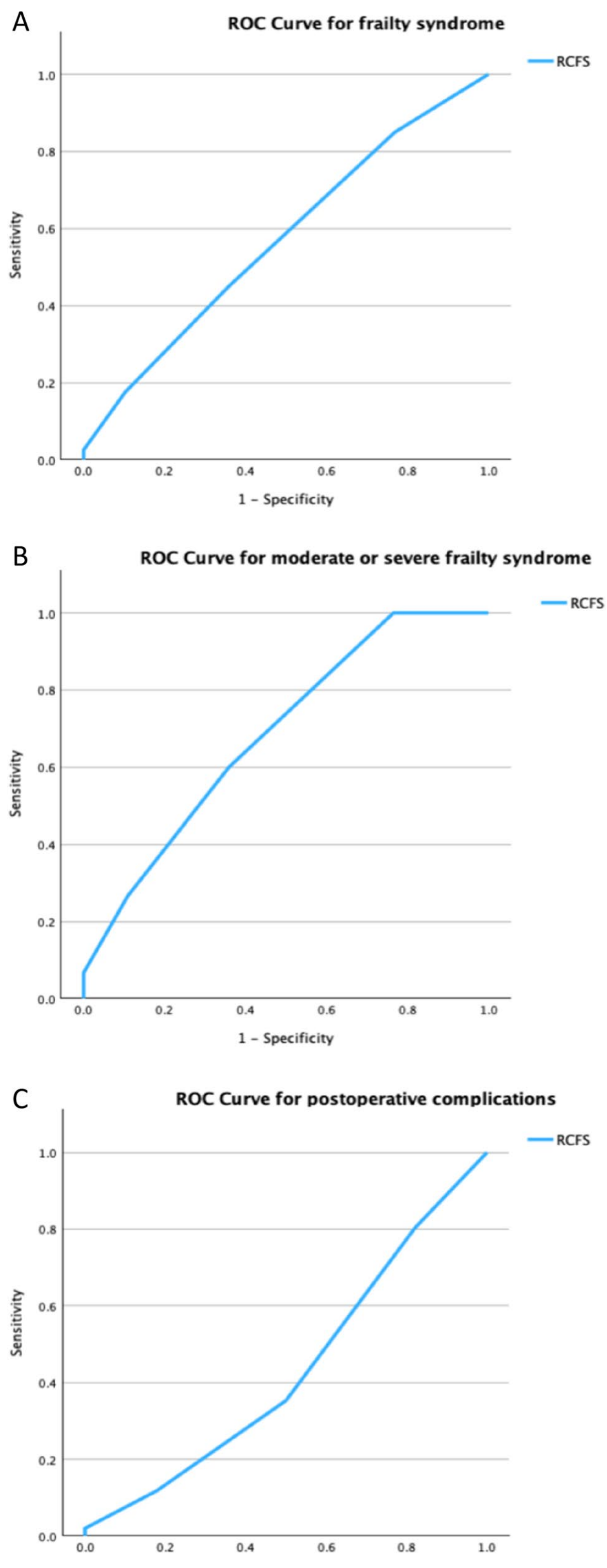

Fig. 1 – ROC curves for RCFS efficacy in detection of frailty syndrome and postoperative complications. A - ROC curve of RCFS for frailty syndrome detection. AUROC=0.571; CI: 0.444-0.697; p=0.064. B - ROC curve of RCFS for moderate or severe frailty syndrome detection. AUROC=0.686; CI: 0.548-0.824; p=0.008. C - ROC curve of RCFS for postoperative complication detection. AUROC=0.435; CI: 0.300-0.570; p=0.344.

No significant differences were found between the fit and the moderate or severe frailty patients. Nevertheless, the subgroups were very small therefore the reliability of subgroups analysis is limited.

The relationship of radiological parameters and postoperative complications was also evaluated. This analysis revealed significantly higher AAC, lower psoas muscles radiodensity and lower kidney radiodensity in patients with postoperative complications. These results seem consistent with previous literature findings. Several studies have demonstrated that higher AAC is associated with a greater risk of complications after abdominal surgery [62, 63], while lower psoas muscle radiodensity is linked not only to a higher risk of postoperative complications, but also to a longer length of stay and increased mortality [64]. We have not identified studies analyzing the relationship between kidneys radiodensity and postoperative complications, thus this result should be interpreted with caution.

The final step of the analysis of measurements involved creating ROC curves for both individual radiological parameters and RCFS. Among individual parameters, only AAC showed a statistically significant AUROC. As, despite AAC none of the radiological domains proved to be significant standalone, we proposed RFCS to investigate a more comprehensive look at the CT scan. The AUROC for RCFS was significant only for prediction of moderate and severe frailty, and it did not show a significant relationship with frailty syndrome itself or postoperative complications. This could be due to the relatively small sample, as several domains of the RFCS tend to differ significantly between the groups. The score should be validated in a larger cohort.

The multiplicity of methods of AAC evaluation analyzed in this study was caused by the lack of an unequivocal reference method [40]. Measurement methods were based on the Agatston et al. calcification definition [38], but due to technological software limitations the original method could not be applied. Due to that, we proposed to measure the radiodensity of the aorta which would be increased in the aorta with a greater amount of calcification or the calcifications volume (with standardization for aorta volume). Two visual scales to evaluate the burden of calcification were also proposed (ACVS, ACCV) and in current study they have been proved to have the best efficacy in frailty prediction. The parameter that was included into multivariable regression model and RFCS as a representative of AAC was MMAS radiodensity as it was considered as most objective and replicable method.

Moreover, an interesting finding was the difference in the psoas muscle HU, but not the area itself. This indicates that not only the quantity of muscles, but also their quality may play a significant role in the pathogenesis of frailty syndrome. Therefore, this parameter should not be omitted during muscle assessment.

Kołodziejska et al. showed that osteopenia was the best predictor of 30-day mortality in emergency surgical intervention, while sarcopenia, aortic calcifications, mean kidney volume did not predict poor outcomes or perioperative morbidity. However, the study suggested that they may still be useful for frailty screening [11]. In our study, we found that psoas muscle area, kidney volume and osteopenia or sarcopenic obesity are not significantly correlated with frailty diagnosis. The burden of abdominal aorta calcification turned out to be significantly higher in frail patients that in fit. This is an interesting finding considering where most individual radiographic markers fell short a subjective analysis of aorta composition was the best predictor of frailty. The importance of AAC in terms of postoperative morbidity was also visible in Kołodziejska et al. univariate analysis and in other studies [15–19].

Lauerman et al. in their analysis showed similar conclusions concerning individual radiographic markers. Additionally, they attempted to create a composite radiographic marker that better predicted poor discharge disposition in trauma. It consisted of measurements derived from abdominal, thoracic (emphysema), and head and neck (CNS) CT scans [10]. Our modified composite score focused on abdominal CT markers which resulted in similar AUROC. Lauerman and colleagues found an AUROC of 0.659 for their 8-part composite marker (sarcopenia, osteopenia, vascular calcifications, sarcopenic obesity, emphysema, renal volume, cervical spine degeneration, cerebral atrophy) and our study found an AUROC of 0.652 for 5-part composite score (sarcopenia, sarcopenic obesity, osteoporosis, aorta calcification, and renal atrophy). The major difference is that we tested it against frailty determined by CGA whereas Lauerman et al. used discharge disposition. This indicates the possibility of improving the predictive value of radiographic markers by finding a composite score that gives the best results. This is a challenge for future studies. Thus far osteopenia and atherosclerosis seem to have the biggest predictive value.

In this study we analysed planned admissions of surgical patients which differentiates it from mentioned studies where frailty was examined in trauma.

Our study has several limitations. One of them is a heterogeneous and relatively small group in terms of surgery indications which is important when discussing complications. Some of the patients treated in our centre had CT performed at external facilities, causing their exclusion from the study and reducing the group size. Another limitation was also imperfect automatic aorta calcification measurement which was observed to not always recognise aorta and calcification plaques correctly.

Strengths of our study include full CGA conducted prospectively and a comprehensive analysis of various radiological parameters, both individually and as a radiological composite frailty score, which represents an innovative approach.

Overall, the investigation of individual radiological markers does not yield promising results, except for AAC, which tends to be significantly higher in frail patients. A composite radiological score may have potential application in frailty screening and quantitative evaluation after prior validation. There is still a vast lack of evidence for clinical implementation, but there is room for future investigation. CGA remains the preferred method for frailty evaluation in patients [8].

Conclusions

Among the analyzed CT parameters, only abdominal aorta calcification was a factor significantly determining frailty syndrome occurrence, while sarcopenia, osteopenia, renal atrophy, and sarcopenic obesity did not differ significantly between fit and frail group. Despite reaching statistical significance, the correlation of AAC and frailty syndrome was weak. The proposed Radiological Composite Frailty Score might be an effective tool in frailty syndrome detection, but it requires further analysis and validation in a larger, more homogenous group. In terms of secondary outcomes, RCFS did not show significant efficacy in predicting postoperative complications.

Abbreviations

AAC	Abdominal aorta calcification
ACCV	Number of aortic calcifications calculated visually
ACVS	Aorta calcification visual scale
ADL	Activities of Daily Living
AMAS	Automatically measured aorta segment
BOMC	Blessed Orientation Memory Concentration
CCI	Comprehensive Complication Index
CGA	Comprehensive Geriatric Assessment
CT	Computed tomography
IADL	Instrumental Activities of Daily Living
ICU	Intensive care unit
IQR	Interquartile range
MMAS	Manually measured aorta segment
MOS	Medical Outcomes Study
RCFS	Radiological composite frailty score
TP	Total psoas muscle
TPA	Total psoas area

Authors' contributions

All authors have contributed significantly to the preparation of this manuscript. J.K. and J.Krz. have created the research concept and design. J.Krz., S.W., and A.Y. were responsible for data collection and assembly. J.K., J.Krz. S.W. performed data analysis and interpretation. J.Krz. and S.W. prepared tables and figures. All authors participated in writing the article, its critical revision and final approval.

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Data availability

Although informed consent for the publication of the study was obtained, explicit consent for publicly sharing the raw data was not acquired from the included patients. Consequently, the data analyzed in this study are not publicly available.

Declarations

Ethics approval and consent to participate

The authors declare that the research was conducted in accordance with the Declaration of Helsinki and was approved by the Bioethics Committee of Jagiellonian University (number of approval: 1072.6120.125.2020).
All patients included in the study provided voluntary informed consent to participate. They were informed about the purpose of the study and methodology of the study. The study was based on clinical data, and did not involve any interventions which could cause harm to the patients.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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