Research Article

CT-Quantified Adipose Tissue Distribution: Risk or Protective Factor for Complications after Rectal Cancer Surgery?

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Keywords

Rectal neoplasms · Morbidity · Body composition · Adipose tissue · Obesity paradox · Computed tomography

Abstract

Purpose: Obesity is associated with increased incidence and mortality in rectal cancer (RC). However, an obesity paradox in the sense of a protective effect of obesity is discussed controversially. We evaluated whether adipose tissue distribution has an impact on medical (MC) and surgical complications (SC) after RC surgery. **Methods:** A total of 296 RC patients underwent oncological surgery and multidetector CT with quantification of total (TAT), visceral (VAT), and subcutaneous adipose tissue (SAT). Logistic regressions on SC (anastomotic leakage [$n = 26$], wound infection [$n = 58$], bleeding [$n = 12$], abscess [$n = 32$], bladder dysfunction [$n = 24$], burst abdomen [$n = 10$]), and MC (pulmonary [$n = 22$], cardiac [$n = 18$], urinary tract infection [$n = 9$], sepsis [$n = 5$]) were performed. **Results:** High pelvic VAT was associated with reduced risk for overall SC (OR = 0.915, $p = 0.012$) and anastomotic leakage (OR = 0.587, $p =$

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0.024, CI: 0.369/0.934). In contrast, CT-quantified obesity was associated with increased risk for wound infection, bladder dysfunction, burst abdomen, overall MC, and cardiac complications (ORs up to 1.423). BMI was not associated with any SC or MC. **Conclusion:** An obesity paradox with a protective effect of CT-quantified adipose tissue was confirmed for anastomotic leakage and overall SC. In contrast, high adipose tissue was associated with higher risk for other SC and MC. These results show a more complex influence of body composition on MC and SC. CT-quantified obesity is able to provide deeper insights to explain the obesity paradox beyond BMI.

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Introduction

Overweight and obesity are important global health problems associated with increased incidence and morbidity for various diseases [1–3], resulting in an increased all-cause mortality [4, 5]. Recently, conflicting observations have been reported, with a survival advantage for obese and disadvantage in underweight and even normal-weight individuals in specific populations with chronic diseases, described as the so-called obesity paradox [6–8]. This phenomenon was first described in patients on hemodialysis, and later in patients with chronic heart failure, hypertension, coronary artery disease, and type 2 diabetes [8–11]. Chronic diseases aside, in 2008, Mullen et al. [12] showed the highest 30-day mortality for underweight patients in a prospective study of 2,258 patients with major abdominal surgery. In 2009, Mullen et al. [13] confirmed the obesity paradox in a larger prospective cohort with 118,707 individuals undergoing nonbariatric surgery, showing the highest 30-day mortality in underweight and severely obese and the lowest mortality in overweight and moderately obese patients, corresponding to a reverse J-shaped mortality curve.

Rectal cancer (RC) is one of the most common cancer types [14]. Several studies showed that overweight and obesity are associated with increased incidence of RC [2, 15]. Obesity is also associated with an increased risk of recurrence and mortality [16, 17]. Because of increased incidence and mortality of RC in obese individuals on the one hand and the obesity paradox on the other, the role of overweight and obesity in RC still seems contradictory. One reason for conflicting results might be that the majority of studies investigating the obesity paradox were based on BMI [18]. However, BMI lacks a differentiation between muscle and fat mass, or between visceral (VAT) and subcutaneous (SAT) adipose tissue. Therefore, additional studies using methods that more accurately reflect body composition, and specifically adipose tissue distribution, are needed to understand the complex influence of obesity in RC.

This study aims to investigate the influence of obesity on morbidity after RC surgery by analyzing surgical (SC) and medical complications (MC) and their association with CT-quantified adipose tissue distribution in addition to body weight and BMI.

Materials and Methods

Patient Characteristics

A total of 296 patients who underwent RC surgery at our institution between January 2008 and May 2013 were retrospectively enrolled in this study. Patients were consecutively selected by analyzing lists of RC surgery from this institution with review of their charts. Eligibility criteria were: primary diagnosis of RC, procedure of surgery for RC, age ≥ 18 years and availability of a CT scan within 180 days from the date of

Table 1. Characteristics of the study population (n = 296)

Age, mean ± SD, years	63.7±11.9
Sex, n (%)	
Male	210 (71)
Female	86 (29)
BMI	
Mean (SD)	26 (4.2)
Min/max	16/40
Underweight (BMI <18.5), n (%)	10 (3.4)
Normal weight (BMI 18.5–24.99), n (%)	116 (39.2)
Overweight (BMI 25–29.99), n (%)	119 (40.2)
Obese Class I–III (BMI ≥30), n (%)	51 (17.2)
Diabetes mellitus status, n (%)	
Yes	49 (16.4)
No	247 (83.6)
Preoperative fasting glucose level at day of surgery	
Mean ± SD	139.3±33
Min/max	71/313
UICC stage, n (%)	
0	5 (1.7)
I	67 (22.6)
II	75 (25.3)
III	97 (32.8)
IV	52 (17.6)
Type of surgery	
LAR, n (%)	228 (77.0)
HAR, n (%)	12 (4.1)
APR, n (%)	49 (16.6)
PE, n (%)	6 (2.0)
Other, n (%)	1 (0.3)
Stoma, n (%)	
Yes	283 (95.6)
No	13 (4.4)
Height of rectal cancer	
Low rectal cancer (≤5 cm)	109 (36.8)
High rectal cancer (≥6 cm)	165 (55.7)
Missing	22 (7.4)
Neoadjuvant radiotherapy	
Yes	180 (60.8)
No	112 (37.8)
Missing	4 (1.4)
Time of CT scan	
CT scans pre-surgery, n	217
Time, mean (SD), days	27.99 (31.7)
Min/max, days	1/174
CT scans post-surgery, n	79
Time, mean (SD), days	35.3 (40.2)
Min/max, days	2/171
Radiation exposure	
DLP, mGy cm	
Median	603
Q1/Q3 (interquartile range)	400/786
Effective tube current-time product, mAs	
Median	145

Table 1 (continued)

Q1/Q3 (interquartile range)	114/176.5
X-Ray tube voltage, kV	
Median	120
Q1/Q3 (interquartile range)	120/120
Duration of surgery, min	
Mean time (SD)	247.1 (89.7)
Min/max	100.0/720.0
Hospital stay duration (days)	
Mean (SD)	19 (19.0)
Min/Max	2/218

BMI, body mass index; SD, standard deviation; LAR, low anterior rectum resection; HAR, high anterior rectum resection; APR, abdominoperineal resection; PE, pelvic exenteration.

Fig. 1. Area-based quantification of total adipose tissue (**b**; pink color) and visceral adipose tissue (**c**; pink color) at the L3/4 spinal level (**a**; level of measurements indicated by the blue line) of a male patient aged 59 years.

surgery. We retrospectively retrieved abdominal CT scans using the institutional PACS (GE Medical Systems, Little Chalfont, UK). Data on diagnosis, date of surgery, Union for International Cancer Control (UICC) classification and location of tumor, age, sex, height, weight (derived from the anesthesia protocol the day before surgery), BMI, diabetes status, preoperative fasting glucose levels, duration of surgery, type of surgery, length of hospital stay, amount of blood loss, MC (cardiac, pulmonary, sepsis, urinary tract infection [UTI]) and SC during hospital stay (anastomotic leakage, wound infection, bleeding, abscesses, bladder dysfunction, burst abdomen); and presence-status of stoma were abstracted from the hospital information system I.S.-H.*med. (SAP, Walldorf, Germany). For detailed patient characteristics, see Table 1.

Fig. 2. Volume-based quantification of abdominal total adipose tissue (**a**) and visceral adipose tissue (**b**) at the Th11/12 to S1 spinal level (adipose tissue marked in pink) of a male patient aged 59 years.

CT-Based Quantification of Adipose Tissue

Densitometric quantification based on CT scans was performed using a postprocessing software tool (MMPW, CT Volume tool, Siemens Healthcare, Erlangen, Germany). First, area-based quantification of adipose tissue compartments was performed on the L3/4 spinal level (volumetric quantification of selected slice, divided by slice thickness, unit: cm^2) [19–21] (Fig. 1). Additionally, volumetric measurements (unit: cm^3) of the abdominal (Th11/12 to L5/S1 spinal level, Fig. 2) and pelvic adipose tissue (level S1 to upper edge of symphysis, Fig. 3) were performed. Specific regions of interest were manually determined: total adipose tissue (TAT; whole abdominal circumference, see Fig. 1–3) and VAT (by defining the fascial plane of the abdominal muscle wall) were measured. Limits of measurements for selecting specifically adipose tissue were -190 to -30 HU [22, 23]. SAT was calculated by subtracting VAT from TAT [21]. The visceral-to-subcutaneous fat ratio was calculated as VAT/SAT at level L3/4.

Statistical Analysis

Data were managed using a spreadsheet program (Microsoft Office Excel® 2010, Microsoft Corporation, Redmond, WA, USA). Descriptive and statistical analyses were performed using SAS 9.3 (2008, SAS Institute, Cary, NC, USA). Logistic regressions for the impact of adipose tissue on MC and SC were applied. Additionally, multivariate logistic regression models adjusted for age and sex were performed (online suppl. Table 1 and 2; for all online suppl. material, see www.karger.com/doi/10.1159/000499320). Pearson correlations for length of hospital stay, time of surgery, and blood loss with adipose tissue were assessed. All analyses had a statistical power of $\sim 90\%$ and were considered significant at $\alpha = 0.05$.

Fig. 3. Volume-based quantification of pelvic total adipose tissue (**a**) and visceral adipose tissue (**b**) at the level of vertebral body S1 to symphysis (adipose tissue marked in pink) of a male patient aged 59 years.

Results

Distribution of Adipose Tissue

Detailed characteristics of the overall study population, including cancer stages and surgical procedures performed, are provided in Table 1. Mean values and standard deviations of TAT, VAT, SAT, and VAT/SAT at the L3/4 spinal level, resulting from area-based quantification, are provided in Table 2. Volume-based measurements of abdominal and pelvic TAT, VAT, and SAT are provided in Table 2.

Frequency of SC and MC

Within the patient cohort of 296 patients, 103 subjects developed at least one surgical complication during their hospital stay (34.8%). Out of these, wound infection was most frequent with 58 cases (19.9%), followed by abscess with 32 cases (10.8%). Anastomotic leakage occurred in 26 out of 240 patients with anastomosis. Furthermore, 24 patients (8.1%) suffered bladder dysfunction, 12 (4.1%) patients bleeding, and 10 patients (3.4%) burst abdomen (Table 3). MC occurred in 48 out of 296 patients during their hospital stay (16.2%). Most common were pulmonary complications with 22 cases (7.4%), followed by cardiac complications in 18 cases (6.1%). UTI occurred in 9 cases (3.0%) and sepsis or systemic inflammatory response syndrome (SIRS) in 5 cases (1.7%) (Table 3).

Table 2. Distribution of adipose tissue across compartments by area and volume ($n = 296$)

Level of quantification	Adipose tissue compartments			
	TAT	VAT	SAT	VAT/SAT
L3/4				
Mean area, cm ²	371.2	175.4	199.8	0.94
SD	155.0	90.9	93.1	0.49
Female mean area, cm ²	345.1	126.4	229.6	0.54
SD	162.2	73.8	112.4	0.32
Male mean area, cm ²	380.5	195.5	189.2	1.09
SD	151.8	89.8	83.0	0.46
Volume abdomen				
Mean volume, cm ³	6,437.6	3,201.0	3,278.9	–
SD	2,887.5	1,622.4	1,558.7	–
Female mean area, cm ²	5,229.1	2,107.5	3,543.7	
SD	2,496.6	1,139.2	1,757.1	
Male mean area, cm ²	6,750.9	3,640.6	3,210.2	
SD	2,909.5	1,581.3	1,504.4	
Volume pelvis				
Mean volume, cm ³	3,036.9	918.4	2,165.6	
SD	1,353.8	374.7	1,123.0	–
Female mean area, cm ²	3,576.1	874.8	2,840.6	
SD	1,486.5	634.6	1,284.5	
Male mean area, cm ²	2,897.1	936.0	1,990.7	
SD	1,288.0	378.2	1,012.2	

SD, standard deviation; TAT, total adipose tissue; VAT, visceral adipose tissue; SAT, subcutaneous adipose tissue; VAT/SAT, visceral fat ratio VAT/SAT.

Table 3. Incidence of surgical and medical complications after rectal cancer surgery ($n = 296$)

Type of complication	<i>n</i> (%)
Surgical (overall)	103 (34.8)
Surgical complications (descending order)	
Wound infection	58 (19.9)
Abscess	32 (10.8)
Anastomotic leakage ($n = 240$) ^a	26 (10.8)
Bladder	24 (8.1)
Bleeding	12 (4.1)
Burst abdomen	10 (3.4)
Medical (overall)	48 (16.2)
Medical complications (descending order)	
Pulmonary	22 (7.4)
Cardiac	18 (6.1)
Urinary tract infection	9 (3.0)
Sepsis/SIRS	5 (1.7)

^a Out of 240 patients with anastomosis.

Table 4. Logistic regression of adipose tissue compartments on surgical complications, $n = 296$ (total), for anastomotic leakage, $n = 240$ (patients with anastomosis)

Type of complication	Adipose tissue compartment	OR	Confidence interval	p value (χ^2)
Surgical complications (total)	VAT _{pelvis}	0.915	0.854/0.981	0.012
Anastomotic leakage	VAT _{pelvis} ^I	0.587	0.369/0.934	0.024
Wound infection	SAT _{pelvis} ^I	1.138	1.015/1.275	0.027
	TAT _{pelvis} ^I	1.106	1.002/1.22	0.046
Bleeding	none			
Abscess	none			
Bladder dysfunction	TAT _{abd} ^I	1.118	1.00008/1.249	0.0498
	VAT _{abd} ^I	1.196	1.015/1.409	0.032
	VAT _{L3/4} ^I	1.157	1.009/1.326	0.036
Burst abdomen	TAT _{abd} ^I	1.321	1.097/1.591	0.003
	VAT _{abd} ^I	1.336	1.052/1.697	0.017
	SAT _{abd} ^I	1.423	1.089/1.86	0.01
	TAT _{pelvis} ^I	1.354	1.12/1.648	0.003
	SAT _{pelvis} ^I	1.365	1.112/1.677	0.003
	TAT _{L3/4} ^I	1.135	1.01/1.275	0.033
	VAT _{L3/4} ^I	1.257	1.029/1.536	0.025

TAT, total adipose tissue; VAT, visceral adipose tissue; SAT, subcutaneous adipose tissue; abd, abdominal volume TH11/12 to L5/S1; pelvis, pelvic volume S1-upper edge symphysis; L3/4, lumbar vertebra level L3/L4. Odds ratios and corresponding confidence intervals were scaled to reflect a change of 10 units for body size-adjusted values (I), a change of 50 units (cm²) for adipose tissue area L3/4, a change of 100 units (cm³) for volume-based adipose tissue parameters, and a change of 0.1 units for VAT/SAT. ^I Index after adjustment of value for body size (cm²/m²) or (cm³/m²).

Significance of Adipose Tissue Compartments Concerning SC

High amounts of pelvic VAT were associated with a decreased risk for overall SC (OR = 0.915, $p = 0.012$, CI: 0.854/0.981) and a lower risk for anastomotic leakage (OR = 0.587, $p = 0.024$, CI: 0.369/0.934). By contrast, high amounts of pelvic SAT and TAT were associated with a higher risk for wound infections (SAT: OR = 1.138, $p = 0.027$; TAT: OR = 1.106, $p = 0.046$). Moreover, high abdominal VAT and TAT values were associated with a higher risk for bladder dysfunction (TAT: OR = 1.118, $p = 0.0498$; VAT: OR = 1.196, $p = 0.032$). Similarly, high amounts of all pelvic and abdominal adipose tissue compartments (TAT, VAT, and SAT) were associated with an increased risk for burst abdomen (OR: from 1.135 to 1.423; $p < 0.033$) (Table 4). Regarding bleeding and abscesses, no association with the extent of adipose tissue was found. There was also no significant impact of BMI or overall body weight on all above-mentioned types of complications (nonsignificant results not shown). After adjusting for sex and age in the multivariate logistic regression, the above described results remained significant with exceptions of TAT in wound infection and bladder dysfunction and VAT in burst abdomen and bladder dysfunction (online suppl. Table 1).

Significance of Adipose Tissue Compartments Concerning MC

High amounts of abdominal and pelvic TAT and SAT were associated with a higher risk for overall MC (OR: from 1.11 to 1.193, $p < 0.032$). In particular, patients with high amounts of pelvic and abdominal TAT, VAT, and SAT showed an increased risk for cardiac complications

Table 5. Logistic regression of adipose tissue compartments on medical complications ($n = 296$)

Complication	Adipose tissue compartment	OR	Confidence interval	p value (χ^2)
Medical (total)	TAT _{abd} ^I	1.11	1.009/1.217	0.032
	SAT _{abd} ^I	1.183	1.016/1.377	0.031
	TAT _{pelvis} ^I	1.157	1.042/1.286	0.007
	SAT _{pelvis} ^I	1.193	1.057/1.346	0.004
Pulmonal	none			
Cardiac	TAT _{abd} ^I	1.197	1.038/1.381	0.013
	VAT _{abd} ^I	1.284	1.066/1.547	0.008
	TAT _{pelvis} ^I	1.214	1.044/1.412	0.012
	SAT _{pelvis} ^I	1.218	1.032/1.438	0.02
	TAT _{L3/4} ^I	1.116	1.01/1.232	0.03
	VAT _{L3/4} ^I	1.191	1.021/1.39	0.026
UTI	VAT/SAT _{L3/4}	0.804	0.649/0.997	0.045
SIRS/sepsis	none			

TAT, total adipose tissue; VAT, visceral adipose tissue; SAT, subcutaneous adipose tissue; abd, abdominal. Odds ratios and corresponding confidence intervals were scaled to reflect a change of 10 units for body size-adjusted values (I), a change of 50 units (cm²) for adipose tissue area L3/4, a change of 100 units (cm³) for volume-based adipose tissue parameters and a change of 0.1 units for VAT/SAT.
^I Index after adjustment of value for body size (cm²/m²) or (cm³/m²).

(OR: from 1.116 to 1.284, $p < 0.031$). A high ratio of VAT/SAT was associated with a reduced risk for UTI (OR = 0.084, $p = 0.045$) (Table 5). There was no significant association of pulmonary complications or SIRS/sepsis with adipose tissue values. Similar to SC, BMI and body weight alone did not correlate with the risk for MC (nonsignificant results not shown). Taken together, except UTI no obesity paradox was detectable concerning MC. After adjusting for sex and age in the multivariate logistic regression, the above-described results remained significant with exceptions of VAT/SAT in UTI and VAT_{L3/4} in cardiac complications (online suppl. Table 2).

Localization of RC and Diabetes Status

There were no statistically significant differences of anastomotic leakages between low and high RC using a Fisher's exact test (results not shown). Thus, no further stratifications were done.

We did not observe any statistically significant differences in complications with respect to the diabetes mellitus status using a Fisher's exact test. Also, there were no significant differences in complications with respect to the preoperative fasting glucose levels measured on the day of surgery using a Kruskal-Wallis test (nonsignificant results not shown).

Length of Hospital Stay, Duration of Surgery, Blood Loss

High pelvic SAT ($r = 0.21$) was positively correlated with the length of hospital stay. Comparable correlations with the duration of hospitalization did not exist concerning BMI or total body weight (Table 6). Concerning duration of surgery, BMI ($r = 0.22$) and body weight ($r = 0.165$) were positively correlated with operating times. Regarding adipose tissue, L3/4 TAT ($r = 0.156$), abdominal VAT ($r = 0.147$), and L3/4 SAT ($r = 0.157$) were likewise positively correlated with duration of surgical procedures (Table 6). Blood loss during surgery was not significantly correlated with any adipose tissue compartment, or with weight or BMI (Table 6). Thus, no obesity paradox was detectable concerning length of hospital stay, duration of surgery, or quantity of blood loss.

Table 6. Pearson correlations of hospital stay duration, operation duration, and blood loss with BMI, weight, and adipose tissue compartments

	Hospital duration <i>r</i> (<i>p</i>)	Operation duration <i>r</i> (<i>p</i>)	Blood loss <i>r</i> (<i>p</i>)
BMI	0.022 (0.7)	0.22 (0.0001)*	0.069 (0.26)
Weight	0.053 (0.36)	0.165 (0.004)*	0.024 (0.7)
TAT _{abd} ¹	0.112 (0.19)	0.159 (0.066)	0.031 (0.743)
TAT _{pelv} ¹	0.158 (0.06)	0.147 (0.08)	0.03 (0.746)
TAT _{L3/4} ¹	0.043 (0.49)	0.156 (0.01)*	−0.07 (0.29)
VAT _{abd} ¹	0.084 (0.16)	0.147 (0.01)*	−0.007 (0.91)
VAT _{pelv} ¹	0.066 (0.27)	0.092 (0.122)	−0.052 (0.42)
VAT _{L3/4} ¹	0.078 (0.18)	0.12 (0.04)*	−0.043 (0.484)
SAT _{abd} ¹	0.134 (0.12)	0.115 (0.18)	0.014 (0.884)
SAT _{pelv} ¹	0.21 (0.01)*	0.123 (0.15)	0.031 (0.742)
SAT _{L3/4} ¹	0.023 (0.72)	0.157 (0.012)*	−0.048 (0.472)
VAT/SAT _{L3/4}	0.016 (0.8)	−0.008 (0.89)	0.0002 (0.98)

$\alpha = 0.5$, n (total) = 296, * $p < 0.05$, significant. BMI, body mass index; TAT, total adipose tissue; VAT, visceral adipose tissue; SAT, subcutaneous adipose tissue; abd, abdominal volume TH11/12 to L5/S1; pelvis, pelvic volume S1-upper edge symphysis; L3/4, lumbar vertebra L3/L4 level. ¹ Index after adjustment of value for body size (cm^2/m^2).

Discussion

This retrospective study investigated the obesity paradox in post-surgery morbidity of RC patients in order to differentiate effects of body composition of adipose tissue beyond BMI on surgical and medical complications.

Regarding adipose tissue and SC, an obesity paradox was confirmed, showing a protective impact of increased pelvic adipose tissue on anastomotic leakage, which was also apparent after adjustment for age and sex. This effect may reflect a mechanical protection of the anastomosis by the surrounding adipose tissue. We also found a protective effect of high pelvic adipose tissue on overall surgical complications, which might be due to anastomotic leakages being one of the most common complications in our patient cohort with 26 cases.

The obesity paradox, however, was not detectable concerning any other type of surgical complication. In contrast, high amounts of adipose tissue yielded a higher risk of wound infection, which is in line with previous studies, and likely due to delayed or impaired wound healing in patients with thick SAT layers [12, 13, 24, 25], or possible comorbidity with diabetes mellitus. Bladder dysfunctions were likewise associated with high amounts of VAT and TAT, which could be caused by more complex technical conditions during surgery, prompted by reduced visibility and impaired exposure of the fat-containing pelvis. The risk for burst abdomen was likewise increased with higher amounts of all adipose tissue compartments (VAT, SAT, and TAT), probably due to increased intraabdominal pressure, impairment of wound healing and more complex surgical conditions. BMI alone, however, showed no influence regarding any of the surgical complications mentioned above, which is on par with other studies [26].

Regarding MC, high amounts of adipose tissue were associated with increased overall occurrence of MC (in case of SAT and TAT), and increased cardiac complications (in case of TAT, VAT, SAT). Consistent with this finding, Lopez-Delgado et al. [27] showed an increase in cardiac complications (myocardial infarction) following cardiac surgery in obese patients (characterized by BMI). There was, however, no association between adipose tissue mass and pulmonary

complications or sepsis/SIRS in our present study. This differs from previous findings by Lopez-Delgado et al. [27], who detected increased rates of septicemia after cardiac surgery in the obese. Again, BMI alone had no significant influence on MC in our study population.

Increased adipose tissue compartments, but not BMI or body weight, were positively correlated with the length of hospital stay, which was also seen by Tsujinaka et al. [25], Chern et al. [29], and Heus et al. [28], who also observed a prolonged hospital stay in obese. Regarding surgery duration, weight, BMI, and all adipose tissue compartments were positively correlated, probably due to aggravated surgical conditions with reduced visibility. This was also seen by Tsujinaka et al. [25] and Chern et al. [29], who also observed a prolonged surgery duration in obese. There was no significant correlation of blood loss with any adipose tissue compartment as well as weight or BMI. In contrast, in a study by Heus et al. [28], high VAT was associated with high perioperative blood loss.

Overall, in our study we detected both protective and negative effects of adiposity regarding SC and MC after RC surgery. Interestingly, BMI and body weight alone showed mostly no influence, while exact fat distributions as measured by CT did clearly (both positively and negatively) correlate with various complications. However, in the vast majority of 42 studies conducted in 2014, the obesity paradox was defined by BMI ($n = 31$), followed by other surrogate metrics ($n = 7$), and only a minority of 4 studies used methods reflecting the body composition more exactly [18]. This underlines that BMI, which is used as the mainstay in most studies concerning the obesity paradox, is probably not a sufficiently reliable tool for estimating the effects of body composition on surgical outcomes. Some of the conflicting results, obtained in previous studies applying the BMI, may be a result of this limitation.

Our study has the following limitations: it is designed as an explorative retrospective study to identify potential adipose tissue parameters with influence on the most common types of surgical and medical complication after RC surgery. Because of the limited number of overall patients and complication events in our study collective, the clinical relevance of our significant findings needs to be validated. To further investigate the relevance of the above-mentioned findings and the associations of the adipose tissue compartments with rarer complications, higher overall patient numbers are needed to avoid potential errors of multiple testing. In 153 of 296 cases, patients were entirely within the field of view (FOV) of the CT scanner, allowing for documentation of all parameters. In another 101 patients, the L3/4 spinal level was completely within the FOV, enabling analysis of all parameters at L3/4 as well as pelvic and abdominal VAT, but not pelvic SAT. Forty-four patients were not entirely within the FOV of the CT scanner; thus, proper quantification of TAT and SAT in these patients was not possible. However, pelvic VAT was documented. We included CT scans of patients within 180 days from the surgery date to increase the number of patients included in this study. However, the mean time before and after surgery was 28 and 35 days, respectively (Table 1). This is a single-center study in a university hospital setting, with a potential patient selection bias. As a retrospective study, this study includes all documented complications, which occurred during the hospital stay. Later complications are not documented. Additionally, data of weight were collected using the anesthesia protocol of the date of surgery. There are no follow-up data of weight during the hospitalization time.

In conclusion, our study confirmed an obesity paradox with a protective effect of high adipose tissue regarding two types of complications (e.g., anastomotic leakages and overall surgical complications). On the other hand, we found an increase in complications in patients with high amounts of adipose tissue (e.g., wound infection, burst abdomen, bladder dysfunction, MC). However, BMI showed no influence on these complications. These findings show a more complex influence of body composition on MC and SC. CT-quantified obesity is able to provide deeper insights to explain the obesity paradox beyond BMI.

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Statement of Ethics

This retrospective study has been approved by the local institutional review board.

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The authors of this article declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

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Author Contributions

J.N. prepared the manuscript and had the primary responsibility for its final content. All authors critically revised the manuscript and approved its final content. A.B. evaluated the imaging and clinical data; J.B. and B.G. carried out the statistical analyses; A.B., J.B., J.N., M.S., A.U., C.M.U., H.U.K. designed the trial. C.M.U., M.S., Y.K., A.U. organized the trial and provided the data.

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