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TITLE PAGE – Original Article

Preoperative Psoas Muscle Size and Radiodensity Predict Mid-Term Survival and Quality of Life after Fenestrated-Branched Endovascular Aortic Repair

Jussi M. Kärkkäinen MD PhD[1], Emanuel R. Tenorio MD PhD[1], Niku Oksala MD PhD DSc(med)[2], Thanila A. Macedo MD[1], Sen Indrani MD[1], Bernardo C. Mendes MD[1], Randall R. DeMartino MD[1], Michael J. Jacobs MD PhD[3], Barend Mees MD PhD[3] and Gustavo S. Oderich MD[1 *]

From the [1]Advanced Endovascular Aortic Research Program, Division of Vascular and Endovascular Surgery, Mayo Clinic, Rochester, MN, USA; [2]Department of Surgery, Faculty of Medicine and Health Technology, University of Tampere, Finland and Division of Vascular Surgery, Tampere University Hospital, Tampere, Finland and Finnish Cardiovascular Research Center, Tampere, Finland; and [3]Maastricht University Medical Center, Maastricht, Netherlands, European Vascular Center Aachen-Maastricht, Germany and The Netherlands.

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* Corresponding author: Gustavo S. Oderich, Gonda Vascular Center, Mayo Clinic, 200 1st Street SW, Rochester, MN 55902, USA. E-mail: oderich.gustavo@mayo.edu

Abstract:	298/300 words
Body:	4070/4000 words, references are included in the word count
Tables/figures:	7/7 tables and figures (3 tables, 4 figures)
Supplements:	5 supplementary tables, 3 supplementary figures

Abstract (298/300 words)

Objective:

To investigate the association of psoas muscle area (PMA) and density (PMD) with survival and quality of life (QOL) after fenestrated-branched endovascular aortic repair (F-BEVAR).

Methods:

The study included 244 consecutive patients enrolled in a prospective study to investigate outcomes of F-BEVAR. Preoperative computed tomography angiography was used to measure PMA (cm^2) and PMD (Hounsfield unit, HU) at L3-level. Lean psoas muscle area (LPMA) was calculated (PMA×PMD). Patients were divided into two groups using LPMA cut-point based on Cox hazard model. Group A was defined as LPMA≥350 (n=79) and group B as LPMA<350 cm^2×HU (n=165). QOL was assessed at baseline and 12 months using SF-36 survey.

Results:

Patients in Group A were younger (mean age, 72±8 vs 76±7 years, P<.001), more often males (95% vs 59%, P<.001) and had higher body mass index (30±6 vs 27±5 kg/m^2, P=.001). There were no major differences in comorbidities, aneurysm extent and procedural measures between the groups. Thirty-day mortality (0% vs 0.6%, P=1.00) and major adverse event rates (15% vs 24%, P=.18) were similar in Group A and B. At 3 years, patient survival was 94±3% in Group A and 75±4% in Group B (hazard ratio [HR] 0.20, 95% confidence interval [CI] 0.07-0.56, P=.002). The 3-year survival difference was even more prominent in patients aged ≥75 years: 100% for Group A and 72±5% for Group B (HR 0.12, 95% CI 0.02-0.86, P=.035). Group A patients had significantly higher QOL scores at baseline and 12 months. LPMA was the strongest independent predictor of survival during the follow-up in multivariable analysis (adjusted HR 0.59 per one standard deviation, 95% CI 0.40-0.87, P=.008).

Conclusions:

A high LPMA was independently and strongly associated with better mid-term survival and quality of life after F-BEVAR. LPMA may help to identify best candidates for F-BEVAR among elderly patients.

Keywords:

psoas, sarcopenia, frailty, fenestrated, branched, endovascular aortic repair

What this paper adds: **(99/100 words)**

This study investigated a novel surrogate measure of sarcopenia called lean psoas muscle area (LPMA) and its feasibility as a predictor of survival, outcomes and quality of life after fenestrated-branched endovascular aortic repair (F-BEVAR). LPMA was calculated by multiplying psoas muscle area with radiodensity measured from a single axial preoperative computed tomography angiography slice at L3 level. LPMA proved to be the strongest independent preoperative predictor of mid-term survival after F-BEVAR, especially in the elderly. In addition, high LPMA was associated with better quality of life after repair. Thus, LPMA can be used to identify suitable candidates for F-BEVAR.

Introduction

Fenestrated-branched endovascular aortic repair (F-BEVAR) has allowed treatment of pararenal and thoracoabdominal aortic aneurysms (TAAAs) in elderly and fragile patients who would otherwise be unfit for open surgical repair (1). The primary treatment goal is prevention of aneurysm rupture and aortic-related death, prolonging overall survival. However, postoperative complications, re-interventions and the requirement for life-long surveillance may compromise the patient's quality of life (2). The question for many elderly patients with complex aneurysms is not whether the procedure is technically feasible, but rather if repair should be indicated in patients with relatively short life expectancy or when treatment may compromise the patient's ability to live independently. In many patients, operative risk and life expectancy can be difficult to determine. Comorbidities, larger aneurysm size and more extensive aneurysmal disease have been strongly associated with higher mortality, whereas age alone is a poor predictor of survival after F-BEVAR (3,4). Due to the disparity between chronological and biological age, there is a need for better tools to determine operative risk and life expectancy.

Frailty is a complex process of age-associated decline in overall physiologic reserve and functioning (5,6). Frailty appears to be superior to many conventional anesthesiologic risk scores in estimating survival after surgical procedures (7). However, frailty can be exhaustively difficult to determine; there are currently more than 70 assessment tools and no agreement on how to measure it (8). Sarcopenia is a component of frailty characterized by loss of skeletal muscle mass and it has been associated with an increased risk of all-cause mortality and functional decline (9). Although there is currently no consensus on the definition, measurement of cross-sectional psoas muscle area (PMA) from axial computed tomography (CT) images has been shown to be a reproducible and convenient surrogate for sarcopenia (10-13). A recent systematic review of 24 studies involving 5267 patients undergoing abdominal surgery for various conditions showed that presence of

sarcopenia, assessed by peri-operative CT, is associated with worse long-term survival and significant increase in major post-operative complications and 30-day mortality (14).

In recent years, several authors have published promising results suggesting that PMA could be used as a novel prognostic tool for patient survival after open and endovascular aortic repair of abdominal aortic aneurysms (AAAs) (13, 15-18). The initial enthusiasm was shadowed by two recent studies that failed to replicate these results (19,20). However, all these previous studies evaluated only muscle size as a predictor. This does not take the importance of muscle quality over quantity into account. Indeed, Lindström and colleagues demonstrated that PMA alone was not sufficient to predict mortality among 301 patients who underwent elective open AAA repair. Their group discovered that lean psoas muscle area (LPMA), a composite of psoas muscle size and radiodensity, was independently associated with patient survival in multivariable analysis (12). The association of psoas muscle measurements, including PMA and psoas muscle density (PMD), with treatment outcomes and survival has not yet been studied in patients with complex aneurysms undergoing F-BEVAR. Moreover, association of sarcopenia with quality of life after aneurysm repair has not been investigated. The aim of this study was to examine the association of PMA and PMD, measured from preoperative CT angiography (CTA), with mid-term survival (primary end point), in-hospital outcomes and quality of life (secondary end points) after F-BEVAR of pararenal aneurysms and TAAAs.

Methods

The study cohort included patients enrolled in a prospective non-randomized single-center study approved by the Institutional Review Board. Participation required informed consent. The F-BEVAR was performed using manufactured patient-specific or off-the-shelf Cook Zenith (Cook Medical, Inc., Bloomington, Ind) fenestrated and branched stent grafts under physician sponsored investigational device exemption protocols (numbers G130030 and G130266). A total of 244

consecutive patients were enrolled between November 2013 and March 2018. Patient characteristics, cardiovascular risk factors, operative data, length of hospital stay, and 30-day outcomes were collected prospectively and stored in MEDIRAVE database. Study subjects were scored based on Short Form-36 (SF-36) Quality of Life Questionnaire at baseline and 12 months postoperatively; the SF-36 scores were divided into eight subscales. Deaths were retrieved from the medical records, and the survival status of the study patients was verified utilizing the Accurint® database in September 2018.

CTA analysis was performed retrospectively in a standardized fashion by one experienced vascular surgeon. Preoperative CTA was used to measure PMA and PMD from a single axial slice using freehand drawing tool of the image display software (QReads). The slice was chosen at the level of L3 vertebrae where the lateral tips of both transverse processes were visible (**Figure 1**). The regions of interest (ROIs), hence, the left and right psoas muscles, were carefully drawn with the freehand tool according to the anatomical boundaries. If both transverse processes could not be visualized in one axial image due to oblique orientation of the spine (scoliosis), the left and right psoas muscles were drawn in two separate slices where the corresponding transverse processes were most clearly visible. The area (cm^2) and average radiodensity (Hounsfield unit, HU) of the ROIs in each side were registered. PMA and PMD were defined as the mean value of left and right psoas muscle measurements ($PMA = PMA_{LEFT} + PMA_{RIGHT} / 2$; $PMD = PMD_{LEFT} + PMD_{RIGHT} / 2$). Lean psoas muscle area (LPMA, $cm^2 \times HU$) was calculated by multiplying PMA and PMD ($LPMA = PMA \times PMD$). Psoas muscle index (PMI, cm^2/m^2) was defined as $PMA / Height^2$. If the preoperative imaging was more than 6 months old, postoperative CTA, obtained within one week of the index procedure, was used instead.

Preoperative imaging protocol included CTA of the chest, abdomen and pelvis with contrast bolus tracking; the threshold was usually set at 150 HU at the descending thoracic aorta. The contrast agents used were Omnipaque 350 or 300 (Iohexol), or Isovue 300 (Iopamidol). The amount

of contrast bolus was between 80 to 150 ml depending on patient's weight followed by 30 mL saline flush at a rate of 4-6 ml/s. The amount of contrast was reduced, if necessary, in patients with glomerular filtration rate less than 30 ml/min. CTA slices were reconstructed to the thickness of 1-3 mm (typically 2 mm). Any deviation in the imaging protocol was registered as well as any difficulty in assessing the correct level for the psoas muscle measurements (**Supplementary Table I**). The time from contrast injection to a point when the concentration in the descending thoracic aorta reached 150 HU was registered (hereafter referred to as "CTA bolus-tracking time").

End Points and Statistical Analysis

The primary end point of the study was all-cause mortality during the follow-up. Secondary outcome end points included 30-day mortality, major adverse events, length of hospital stay, discharge status (discharge to home versus transfer to another institution such as skilled nursing facility) and significant decrease (≥10 points) in SF-36 subscale scores between baseline and 12 months. The studied CT variables (PMA, PMD, LPMA and PMI) were first tested for association with the primary end point in univariable Cox regression model and the strongest predictor (LPMA) was chosen for grouping of the patients. An optimal cut point value for LPMA was first estimated based on receiver operator characteristics (ROC) analysis (**Supplementary Figure 1**) and then confirmed by adjusted Cox hazard model using the time-dependent primary end point (**Figure 2**). Based on the optimal cut point, the study patients were divided in two groups; group A – high muscle mass (LPMA≥350 cm^2×HU) and group B – low muscle mass (LPMA<350 cm^2×HU).

Differences between the study groups were analyzed using Fisher's exact test for categorical variables and Mann-Whitney U test for continuous variables. The categorical variables were expressed as numbers and percentages, and continuous variables as mean ± standard deviation (SD) and median with interquartile range (IQR) when appropriate. P-values <.05 were considered statistically significant. For univariable and multivariable analyses, LPMA was standardized using z-scoring. Cox regression univariable analysis was performed for all preoperative variables to

determine significant predictors of survival during the follow-up. All variables with P<.10 in the univariable analysis were included in multivariable Cox model 1, and those variables, that were significantly different (P<.05) between groups A and B, were included in multivariable Cox model 2. The multivariable models were used to determine independent preoperative predictors of survival during the follow-up. Body mass index (BMI) was chosen to represent conventional body mass measures in the multivariable analysis and LPMA for the novel muscle mass measures. The results of the Cox regression analyses were expressed as hazard ratios (HRs) with 95% confidence intervals (CIs). All statistical analyses were performed using SPSS version 24.0 (IBM Corp. Armonk NY, USA).

Results

Patient Characteristics and Preoperative Risk Assessment

There were 244 consecutive patients included in the study. The optimal LPMA cut point was determined at 350 cm^2×HU; one-third of the patients (n=79, 32%) had high muscle mass (group A) based on the cut point whereas two-thirds (n=165, 68%) had low muscle mass (group B). The mean age of the patients was 75±8 years, half were 75 years or older and 71% were male. Patients in group A were younger (72±8 vs. 76±7, P<.001) and more often male (95% vs. 59%, P<.001) compared to group B. There were no statistically significant differences in the prevalence of comorbidities between the groups (**Table I)**.

Patients in group A had a higher mean BMI than patients in group B (30±6 vs. 27±5 kg/m^2, P<.001). Consequently, body surface area and estimated lean body mass were also higher in group A (P<.001). Patients in group A were more often obese; 43% of patients had BMI>30 kg/m^2 in group A compared to 22% in group B (P=.001). Out of 241 patients who had cardiac stress test performed, 21% had a positive test with no differences between the groups. Ejection fraction was measured in 236 patients with no difference in mean values between the groups. American Society

of Anesthesiologists (ASA) scores were similar between the study groups; 28% had score 3 or higher; only three patients had score 4. There were no major differences in aneurysm size and extent between the groups, although 41% of the aneurysms in group B were extent I-III TAAAs compared to 28% in group A (P=.05). The mean PMA was 8.3±2.7 cm^2 (median 8.0 [IQR 6.4-9.8]) and mean LPMA 297±130 cm^2×HU (median 279 [IQR 199-372], **Supplementary Figure 2**). PMA, PMI, PMD and LPMA were all significantly (P<.001) higher in group A (**Table II**).

Procedural Characteristics

F-BEVAR was done using patient-specific devices in 222 (91%) patients and off-the-shelf device was used in 22 (9%). There were no major differences in procedural characteristics between the groups (**Supplementary Table II**). However, the mean operation time was longer in group B (227±71 min vs. 265±87 min, P=.002), and percutaneous femoral access was used slightly more often in group A compared to group B patients (87% vs. 76%, P=.04). Implantation of the aortic stent-graft and all target vessel components was successful in 242 patients (99%).

Primary End Point

Mid-term survival was significantly higher in group A patients (**Figure 3**). At 3 years, survival was 94±3% in Group A and 75±4% in Group B (Log Rank P=.001; HR 0.20, 95% CI 0.07-0.56, P=.002). The survival difference did not change when adjusted for the age, gender and BMI differences between the groups (adjusted HR 0.23, 95% CI 0.08-0.66, P=.006). The study population was divided in half based on the patients' age for further survival analysis using 75 years as a cut point (**Supplementary Figure 3**). The 3-year survival difference was even greater in patients aged ≥75 years: 100% for Group A and 72±5% for Group B (Log Rank P=.011; HR 0.12, 95% CI 0.02-0.86, P=.035). The mean follow-up time was 2.1±1.3 years.

Secondary End Points

The 30-day mortality and major adverse event rates were similar between the study groups. There was only one 30-day death (0.4%) and seven patients (3%) suffered from paraplegia

(**Supplementary Table III)**. Acute kidney injury was more common in group B (4% vs. 14%, P=.02). The mean length of hospital stay was significantly longer in group B (9.0±12.0 vs. 4.7±2.9 days, P<.001). Eighty-two percent of patients were discharged to home with no significant differences between the groups.

Group A patients had significantly (P<0.05) higher mean quality of life scores at baseline and 12 months in 11 of 16 subscales (**Figure 4**). The largest decline in mean scores from baseline to 12 months was observed in Physical Functioning among group B patients. At individual level, patients in group B reported a significant drop between the baseline and 12 months in Role Emotional (P=0.003) and Social Functioning (P=0.02) more often than group A (**Supplementary Table IV**).

Preoperative Risk Factors for Mortality

In univariable analysis (**Supplementary Table V**), predictors of decreased survival were congestive heart failure and ASA score ≥3, whereas hypercholesterolemia, BMI, body surface area, PMD and LPMA were predictors of increased survival. Positive cardiac stress test and ejection fraction did not predict mortality. Furthermore, age was not a significant risk factor for mortality (P=.10). In both multivariable models (**Table III**), LPMA proved to be the strongest independent predictor of survival after F-BEVAR. After z-scoring of LPMA, every SD increase in the parameter yielded 41% decrease in the probability of death during the follow-up (HR 0.59, 95% CI 0.40-0.87, P=.008). Based on the multivariable analysis, congestive heart failure and ASA score ≥3 were independently associated with decreased survival and higher BMI with increased survival.

Discussion

This study showed that PMA alone was not a significant predictor of mortality in this patient population confirming the suspicion raised in the two previous studies by Indrakusuma and Waduud (19, 20). However, we discovered that combining psoas muscle size and radiodensity produced a

parameter (LPMA), which was strongly and independently associated with mid-term survival. Indeed, LPMA was the strongest predictor of survival out of all preoperative variables listed in **Tables 1 and 2**. An increase of one SD (130 cm^2×HU) in LPMA decreased the risk of mortality during the follow-up approximately by 40%. In addition, higher BMI was a predictor of survival whereas congestive heart failure and ASA score of 3 or higher were associated with more than two-times higher mortality during the follow-up. Interestingly, up to 97% of the patients underwent preoperative cardiac stress test and ejection fraction assessment, but these were unable to predict survival during follow-up. In contradiction with previous studies, we did not observe statistically significant association between aneurysm size and extent and survival after F-BEVAR (3,4).

Logically, group A patients were younger, more often male, and had higher mean BMI; all of which are associated with higher muscle mass. After adjusting for these factors, the survival difference between group A and B was unchanged suggesting that sarcopenia may be independent of conventional body mass measures such as BMI. The mortality risk during the follow-up was nearly 80% lower in group A with and without adjustment. Half of the patients were aged 75 years or older; in this subgroup, the survival difference was even greater in favor of the group A with high muscle mass. Hence, the LPMA cut point proved to be especially useful in the elderly patients undergoing F-BEVAR.

Since the majority, two-thirds, of the study patients were below the LPMA cut point and the confidence interval of the hazard model was wide especially in the low end of LPMA, we do not recommend using the current LPMA cut-off to deny patients from treatment. The value of the cut point is to use it as a sign of good life expectancy in elderly patients. For example, if a patient in his/her eighties is under consideration for F-BEVAR, good size and quality of the psoas muscles in preoperative CTA should favor proceeding with the repair with lower threshold than in patients with sarcopenia. In order to create an accurate prognostic calculator for assessing life expectancy at various LPMA values, the sample size would have to be larger warranting further investigation.

Furthermore, there are multiple other factors involved in the decision-making process, such as the aneurysm size, anatomy, rupture risk, conventional preoperative risk factors, patient's preference, etc. All these factors need to be taken into consideration.

Regarding secondary outcome end points, there was only one 30-day death, and therefore, the value of LPMA in predicting 30-day mortality could not be assessed. The low early mortality in this trial highlights that the patients were already carefully selected and had undergone tedious preoperative assessment. LPMA was not associated with major adverse events, although the rate of acute kidney injury was higher in group B; these were mostly minor injuries. The mean length of hospital stay was significantly higher in group B, which could possibly be attributed to sarcopenia. Group A patients had significantly higher quality of life measures at baseline and 12 months. Thus, high LPMA was associated with better quality of life before and after treatment. It appeared that group B patients also declined more often than group A in physical, emotional and social aspects of quality of life during the 12-month period after F-BEVAR. However, this does not necessarily reflect treatment satisfaction since SF-36 is a general, not an aneurysm-specific questionnaire.

The reason why PMA alone was not significantly associated with mortality in this study could be due to that the quality of the muscle may be even more important factor than size. Aging is associated with loss of subcutaneous fat, whereas adipocytes and lipids accumulate in bone marrow, liver and skeletal muscle (21). In particular, fatty infiltration of skeletal muscle (myosteatosis) has been associated with frailty, poor functional performance and mortality (22, 23). Since fat has a lower radiodensity than muscle, we hypothesized that PMD could be a potential surrogate for the quality of the muscle. Kays et al measured body composition at L3 level of 505 treated AAA patients from the Vascular Quality Initiative database with CT available for analysis; nearly 60% of AAA patients were sarcopenic, and the presence of myosteatosis and sarcopenia doubled mortality during the follow-up (24).

LPMA is much easier to measure than the body composition. It takes only few minutes and can be done with basic CT viewing software. The key is to find the correct axial slice at L3 level. The psoas muscles need to be drawn carefully without including the anterior longitudinal ligament inside the ROI. Previous studies have shown good interobserver agreement and reproducibility for PMA and PMD measurements (10-13). We did not have preoperative non-contrast CTs, and therefore, CTA was used. CT with contrast in venous phase should not be used; the enhancement of the psoas muscle might cause variability in radiodensity measurements. The preoperative CTA protocols in this study were standardized with minimal variability, and we assume that the overall effect of contrast enhancement of the psoas muscle in CTA was minimal.

Other possible limitations of this study were the higher proportion of males, younger age and higher BMI in group A. Therefore, all preoperative variables (Table I and II) were tested as potential confounding factors, and the multivariable model was adjusted accordingly. LPMA proved to be associated with mortality independent of these factors. One could argue that the F-BEVAR procedures may have been more complex in group B, because there were more patients with type I-III aneurysms and the mean operation time was longer in this group. However, the absolute differences between the groups with regard to these variables were small and early outcomes were similar in both groups.

Conclusion

A high LPMA was independently and strongly associated with better mid-term survival and quality of life after F-BEVAR. A composite of PMA and PMD may help to identify candidates among elderly patients who benefit most from complex endovascular aneurysm repair. F-BEVAR had less impact in the quality of life after 12 months in those with high LPMA. LPMA can be measured easily from preoperative CTA without additional costs. The measurement of psoas

muscle radiodensity should be included in future studies assessing CT parameters as predictors of survival in patients undergoing vascular surgical procedures.

Conflicts of interest

Dr. Kärkkäinen has received personal research grants from following nonprofit organizations: Paulo Foundation (Finland), The Finnish Medical Foundation, Orion Research Foundation sr (Finland), Finnish Surgical Society, and Finnish Society for Vascular Surgery. Professor Oderich has received consulting fees and grants from Cook Medical, W. L. Gore, and GE Healthcare (all paid to Mayo Clinic with no personal income). Professor Oksala has received research funding from Academy of Finland. These organizations did not have any part in this study.

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Table I. Patient demographics and comorbidities

	All patients (n=244)	Group A High Muscle Mass (n=79)	Group B Low Muscle Mass (n=165)	P value
Mean age, years	75 ± 8	72 ± 8	76 ± 7	<.001
Age ≥ 75 years	127 (52)	29 (37)	98 (59)	.001
Male gender	172 (71)	75 (95)	97 (59)	<.001
Cigarette smoking	212 (87)	69 (87)	143 (87)	1.00
Hypertension	220 (90)	70 (89)	150 (91)	.65
Hypercholesterolemia	201 (82)	66 (84)	135 (82)	.86
Coronary artery disease	126 (52)	41 (52)	85 (52)	1.00
Chronic obstructive pulmonary disease	89 (37)	22 (28)	67 (41)	.07
Chronic kidney disease (stages III-V)	49 (20)	14 (18)	35 (21)	.61
Congestive heart failure	26 (11)	7 (9)	19 (12)	.66
Peripheral artery disease	52 (21)	11 (14)	41 (25)	.07
Diabetes mellitus	36 (15)	12 (15)	24 (15)	1.00
Stroke	24 (10)	5 (6)	19 (12)	.25
Malignancy	53 (22)	16 (20)	37 (23)	.74
Prior aortic repair	95 (39)	32 (41)	63 (38)	.78

Data are presented as n (%), mean ± standard deviation or median (interquartile range).

Table II. Operative risk assessment and CTA measures

	All patients (n=244)	Group A High Muscle Mass (n=79)	Group B Low Muscle Mass (n=165)	P value
Positive cardiac stress test	50/241 (21)	18/78 (23)	32/163 (20)	.61
Ejection fraction, %	58 ± 11	57 ± 10	58 ± 11	.98
Ejection fraction < 30 %	5/236 (2)	1/75 (1)	4/161 (2)	1.00
Baseline GFR	61 ± 19	63 ± 19	60 ± 19	.32
Baseline GFR < 30	10 (4)	4 (5)	6 (4)	.73
ASA score	2.2 ± 0.6	2.1 ± 0.6	2.2 ± 0.6	.22
ASA score ≥ 3	68/242 (28)	19/79 (24)	49/163 (30)	.36
Maximum aneurysm diameter, mm	66 ± 11	65 ± 11	67 ± 12	.39
Aneurysm type				
Pararenal	97 (37)	35 (44)	56 (34)	.12
TAAA extent I-III	90 (37)	22 (28)	68 (41)	.05
TAAA extent IV	63 (26)	22 (28)	41 (25)	.64
Conventional body mass measures				
Body mass index, kg/m^2	28±6	30 ± 6	27 ± 5	<.001
Body mass index > 30 kg/m^2	70 (30)	34 (43)	36 (22)	.001
Body surface area, m^2	2.0 ± 0.3	2.1 ± 0.3	1.9 ± 0.3	<.001
Estimated lean body mass (eLBM)	58 ± 11	55 ± 10	64 ± 10	<.001
Novel muscle mass measures				
Psoas muscle area, cm^2	8.3 ± 2.7	10.9 ± 2.3	7.1 ± 1.8	<.001
Psoas muscle index, cm^2/m^2	2.8 ± 0.8	3.5 ± 0.8	2.4 ± 0.6	<.001
Psoas muscle density, HU	35.7 ± 8.9	41.4 ± 6.1	23.9 ± 8.7	<.001
Lean psoas muscle area, cm^2×HU	298 ± 130	446 ± 101	226 ± 67	<.001
CTA bolus-tracking time to 150 HU	20.5 ± 4.2	20.8 ± 4.3	20.3 ± 4.2	.47

Data are presented as n (%) or mean ± standard deviation.

CTA, computed tomography angiography; GFR, glomerular filtration rate; ASA, American Society of Anesthesiologists; TAAA, thoracoabdominal aortic aneurysm; HU, Hounsfield unit

For males: eLBM = 0.407 × Weight(kg) + 0.267 × Height(cm) - 19.2

For females: eLBM = 0.252 × weight(kg) + 0.473 × height(cm) - 48.3

Table III. Multivariable analysis of preoperative risk factors for long-term mortality.

Cox Regression Multivariable Analysis	Hazard ratio	95 % confidence interval		P value
		Lower	Upper	
Multivariable model 1				
Body mass index	0.93	0.88	0.99	.03
Congestive heart failure	2.33	1.04	5.20	.04
ASA score ≥3	2.19	1.10	4.36	.03
Lean psoas muscle area (per 1 SD)	0.62	0.42	0.94	.02
Multivariable model 2				
Lean psoas muscle area (per 1 SD)	0.59	0.40	0.87	.008

ASA, American Society of Anesthesiologists; SD, standard deviation

Model 1 included variables that were considered significant (P<.10) in the univariable analysis.

Model 2 included preoperative variables that were significantly different in group A compared to group B; age, gender, body mass index and lean psoas muscle area.

Supplementary Table I. Details of the computed tomography angiography (CTA) protocols

CTA available for analysis	244 (100%)
Preoperative CTA used for analysis (preop CTA ≤6 months old)	230 (94%)
Mean time from CTA to surgery	111±57 days
Postoperative CTA used for analysis (preop CTA >6 months old)	14 (6%)
Mean time from surgery to CTA	3±3 days
CTA scan done in the study institution	209 (86%)
CTA scan done elsewhere	35 (14%)
Imaging area; chest, abdomen, pelvis	220 (90%)
Imaging area; abdomen, pelvis	24 (10%)
1-3 mm axial slice thickness	238 (98%)
5 mm axial slice thickness	6 (2%)
Trigger threshold for bolus tracking	
150 Hounsfield units	191 (78%)
120 Hounsfield units	7 (3%)
100 Hounsfield units	3 (1%)
Information unavailable	43 (18%)
Both transverse processes visible in the same axial slice	226 (93%)
Oblique vertebra (psoas muscles measured at two different levels)	18 (7%)
Minor technical challenges in psoas muscle measurement	4 (2%)
Fused lumbar vertebrae	2 (1%)
Extra lumbar vertebra	1 (0.5%)
Severe degeneration of the lumbar spine	1 (0.5%)

Supplementary Table II. Procedural characteristics

	All patients (n=244)	Group A High Muscle Mass (n=79)	Group B Low Muscle Mass (n=165)	P value
Fenestrated-branched device type				
Off-the-self (t-Branch®)	22 (9)	6 (8)	16 (10)	.81
Patient-specific	222 (91)	73 (92)	149 (90)	
Number of incorporated target vessel	3.8 ± 0.6	3.8 ± 0.6	3.8 ± 0.6	.79
Fenestrations	2.6 ± 1.5	2.9 ± 1.5	2.4 ± 1.6	.013
Branches	1.4 ± 1.5	0.8 ± 1.4	1.3 ± 1.3	.015
General anesthesia	244 (100)	79 (100)	165 (100)	1.00
Cerebrospinal fluid drain	166 (68)	50 (63)	116 (70)	.31
Neuromonitoring	170 (70)	51 (65)	119 (73)	.23
Percutaneous femoral access	193 (79)	68 (87)	125 (76)	.04
Upper extremity access	220 (90)	69 (87)	151 (92)	.36
Contrast volume, ml	155 ± 56	153 ± 62	156 ± 54	.31
Operation time, min	252 ± 83	227 ± 71	265 ± 87	.002
Estimated blood loss, ml	464 ± 553	419 ± 518	487 ± 570	.47
Technical success	242 (99)	79 (100)	163 (99)	1.00
Any reintervention before discharge	24 (10)	4 (5)	20 (12)	.11

Data are presented as n (%) or mean ± standard deviation.

Supplementary Table III. Secondary outcome end points

	All patients (n=244)	Group A High Muscle Mass (n=79)	Group B Low Muscle Mass (n=165)	P value
Major adverse event	51 (21)	12 (15)	39 (24)	.18
30-day or in-hospital death	1 (0.4)	0 (0)	1 (0.6)	1.00
Estimated blood loss > 1000 ml	21 (9)	6 (8)	15 (9)	.81
Acute kidney injury (RIFLE)	26 (11)	3 (4)	23 (14)	.02
Risk (↓ GFR > 25 %)	23 (9)	3 (4)	20 (12)	.04
Injury/Failure (↓ GFR > 50 %)	3 (1)	0 (0)	3 (2)	.55
Myocardial infarction	10 (4)	2 (3)	8 (5)	.51
Respiratory failure	8 (3)	0 (0)	8 (5)	.06
Paraplegia	7 (3)	0 (0)	7 (4)	.10
Stroke	7 (3)	0 (0)	7 (4)	.10
Bowel ischemia	3 (1)	0 (0)	3 (2)	.55
Hospital length of stay, days	7.6 ± 10.1	4.7 ± 2.9	9.0 ± 12.0	<.001
Discharge to home	200 (82)	70 (89)	130 (79)	.08

Data are presented as n (%) or mean ± standard deviation.

RIFLE, risk-injury-failure classification; GFR, glomerular filtration rate

Supplementary Table IV. Quality of life outcomes

	All patients (n=244)	Group A High Muscle Mass (n=79)	Group B Low Muscle Mass (n=165)	P value
SF-36 questionnaires completed				
At baseline	237 (97)	75 (95)	162 (98)	.22
At 12 months	161 (66)	63 (80)	98 (59)	.002
At baseline and 12 months	157 (64)	61 (77)	96 (58)	.004
Individuals with significant decrease (≥10 points) in SF-36 scores between baseline and 12 months				
Physical Functioning	64 (41)	19 (31)	45 (47)	.07
Role Physical	62 (40)	21 (34)	41 (43)	.32
Role Emotional	41 (26)	8 (13)	33 (34)	.003
Vitality	69 (44)	21 (34)	48 (50)	.07
Mental Health	35 (22)	9 (15)	26 (27)	.08
Social Functioning	45 (29)	11 (18)	34 (35)	.02
Bodily pain	62 (40)	24 (39)	38 (40)	1.00
General Health	63 (40)	27 (44)	36 (38)	.41

Data are presented as n (%).

Supplementary Table V. Univariable analysis of preoperative risk factors for mortality during the follow-up. Variables with P<.10 and those of special interest are included in the table.

Cox Regression Univariable Analysis	Hazard ratio	95 % confidence interval		P value
		Lower	Upper	
Patient demographics and comorbidities				
Age	1.04	0.99	1.09	.10
Gender, male	0.64	0.33	1.21	.17
Hypercholesterolemia	0.47	0.23	0.95	.04
Chronic obstructive pulmonary disease	1.86	0.99	3.48	.054
Chronic kidney disease (stages III-V)	1.76	0.89	3.48	.10
Congestive heart failure	2.38	1.09	5.17	.03
Operative risk assessment				
Positive cardiac stress test	0.58	0.23	1.49	.26
Ejection fraction	1.01	0.98	1.05	.40
Ejection fraction < 30 %	4.01	0.95	16.85	.06
ASA score	1.68	1.01	2.80	.04
ASA score ≥ 3	2.04	1.05	3.95	.04
Maximum aneurysm diameter (per 1 mm)	1.02	1.00	1.04	.054
Aneurysm type: TAAA extent I-III	1.42	0.75	2.69	.29
Conventional body mass measures				
Body mass index	0.93	0.89	0.98	.009
Body mass index > 30 kg/m^2	0.34	0.13	0.86	.02
Body surface area	0.34	0.13	0.93	.04
Estimated lean body mass	0.97	0.94	1.00	.05
Novel muscle mass measures				
Psoas muscle area	0.90	0.79	1.02	.11
Psoas muscle index	0.71	0.47	1.08	.11
Psoas muscle density	0.96	0.92	0.99	.02
Lean psoas muscle area (per 1 cm^2×HU)	0.996	0.993	0.999	.008
Lean psoas muscle area (per 1 SD)	0.59	0.40	0.87	.008
CTA bolus-tracking time to 150 HU	0.99	0.91	1.08	.84

TAAA, thoracoabdominal aortic aneurysm; ASA, American Society of Anesthesiologists; SVS, Society for Vascular Surgery; HU, Hounsfield unit; SD, standard deviation

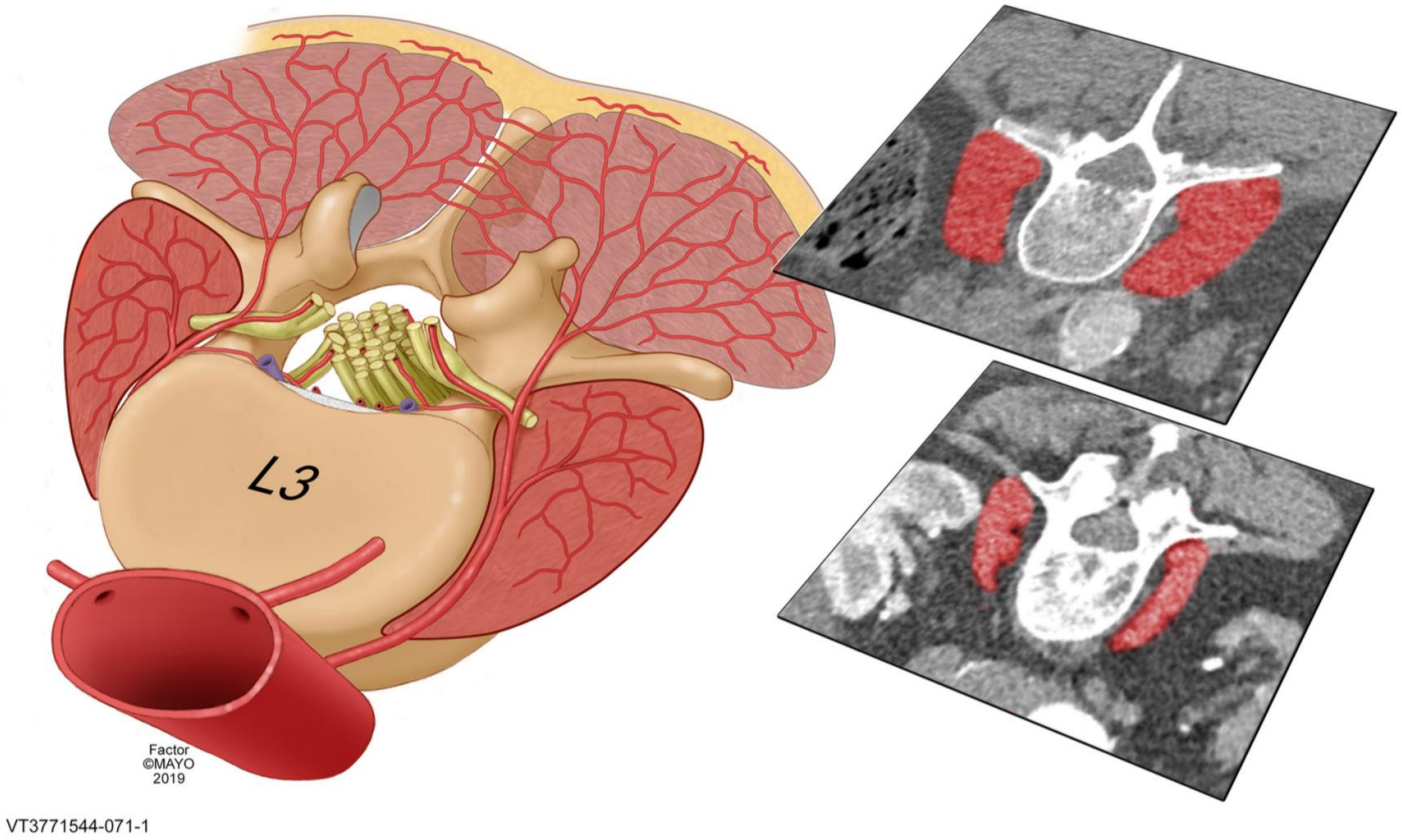


Figure 1. Illustration showing the anatomical landmarks for choosing the correct CT slice at L3 level. The axial slice, where the lateral tips of both transverse processes are best visualized, is chosen for the psoas muscle area and density measurements. The upper CT slice on the right is from a patient with large psoas muscle, and the lower is an example of atrophied psoas muscle. *By permission of Mayo foundation for Medical education and research. All rights reserved.*

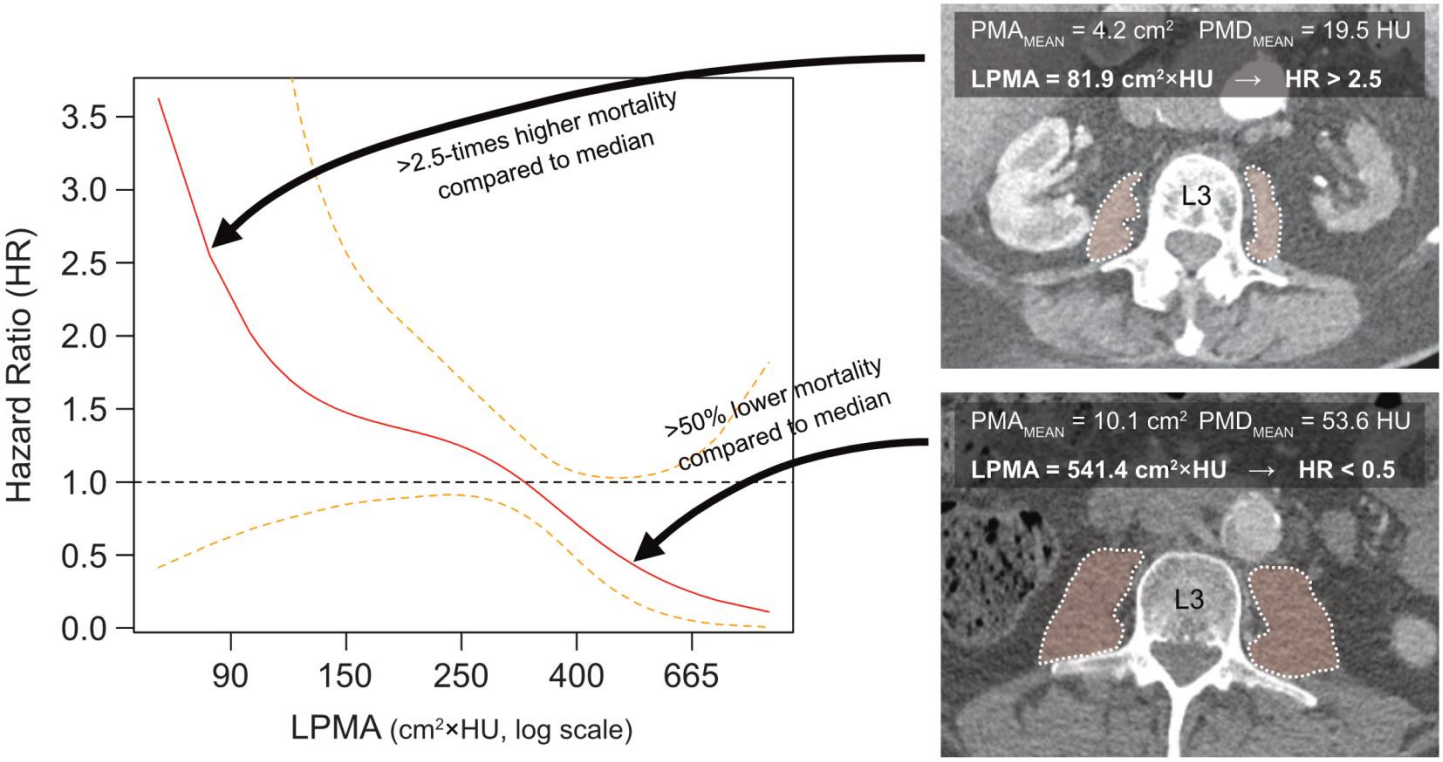


Figure 2. Cox hazard model with splines for mortality risk, adjusted for age, gender and body mass index; the continuous curve shows the hazard ratio (HR) for the time-dependent mortality event as a function of lean psoas muscle area (LPMA = PMA × PMD); the dotted lines represent 95% confidence intervals. The optimal LPMA cut point was approximated at 350 cm^2×HU (HR≈1.0).

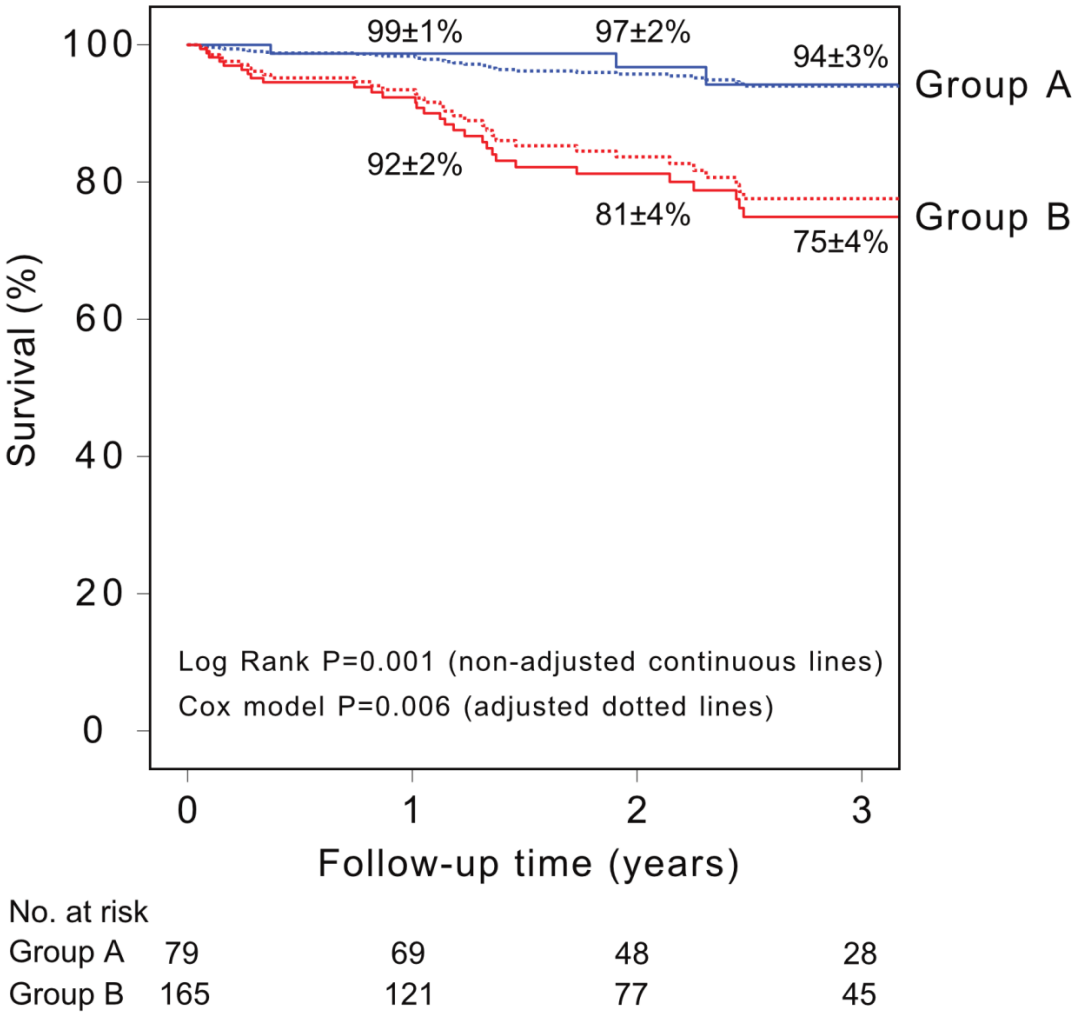


Figure 3. Kaplan-Meier survival estimates for patients with lean psoas muscle area ≥350 cm^2×HU (group A) compared to <350 cm^2×HU (group B) shows significantly higher 3-year survival for group A patients. The dotted line is adjusted for age, gender and body mass index using the Cox model.

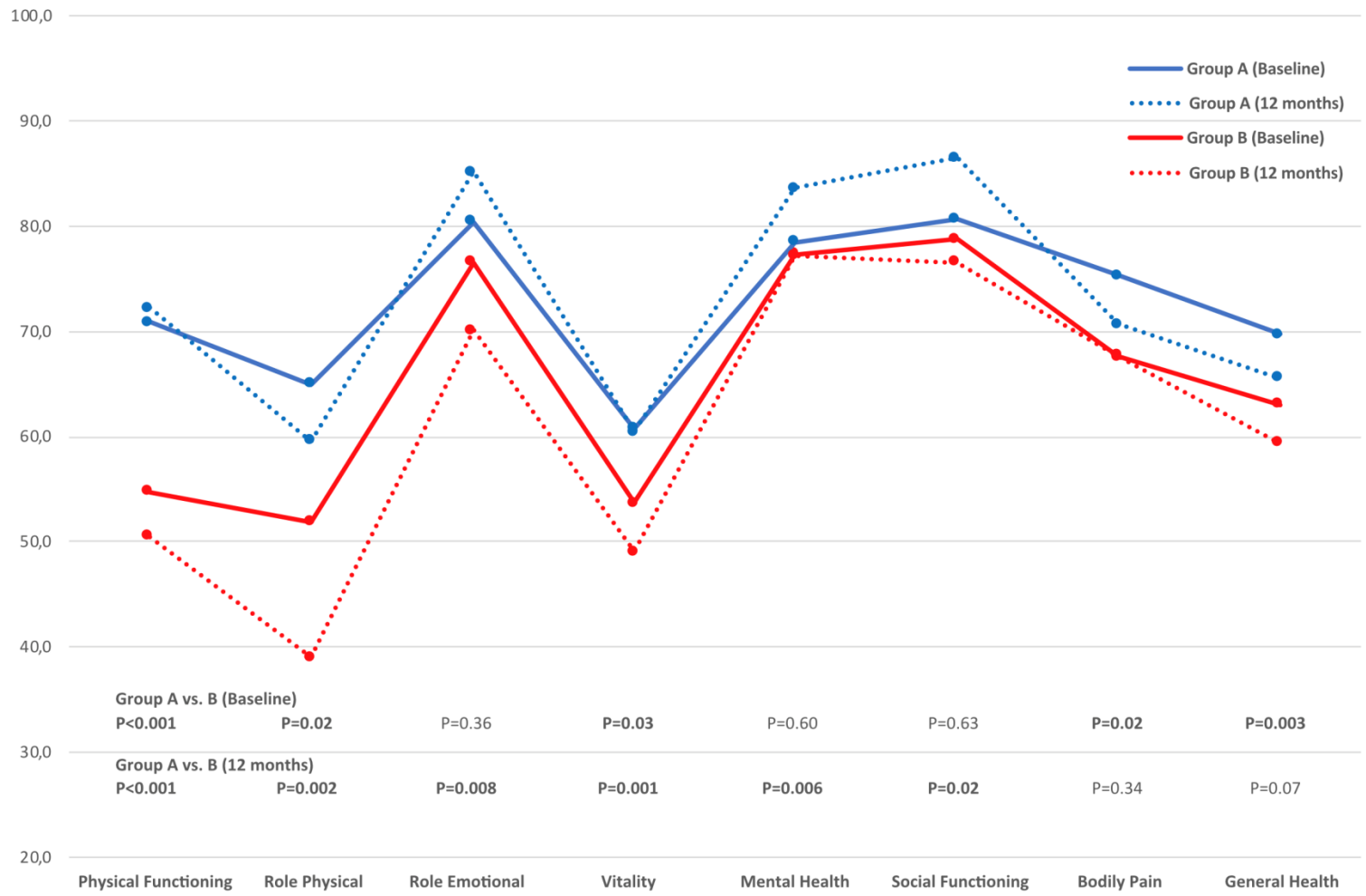
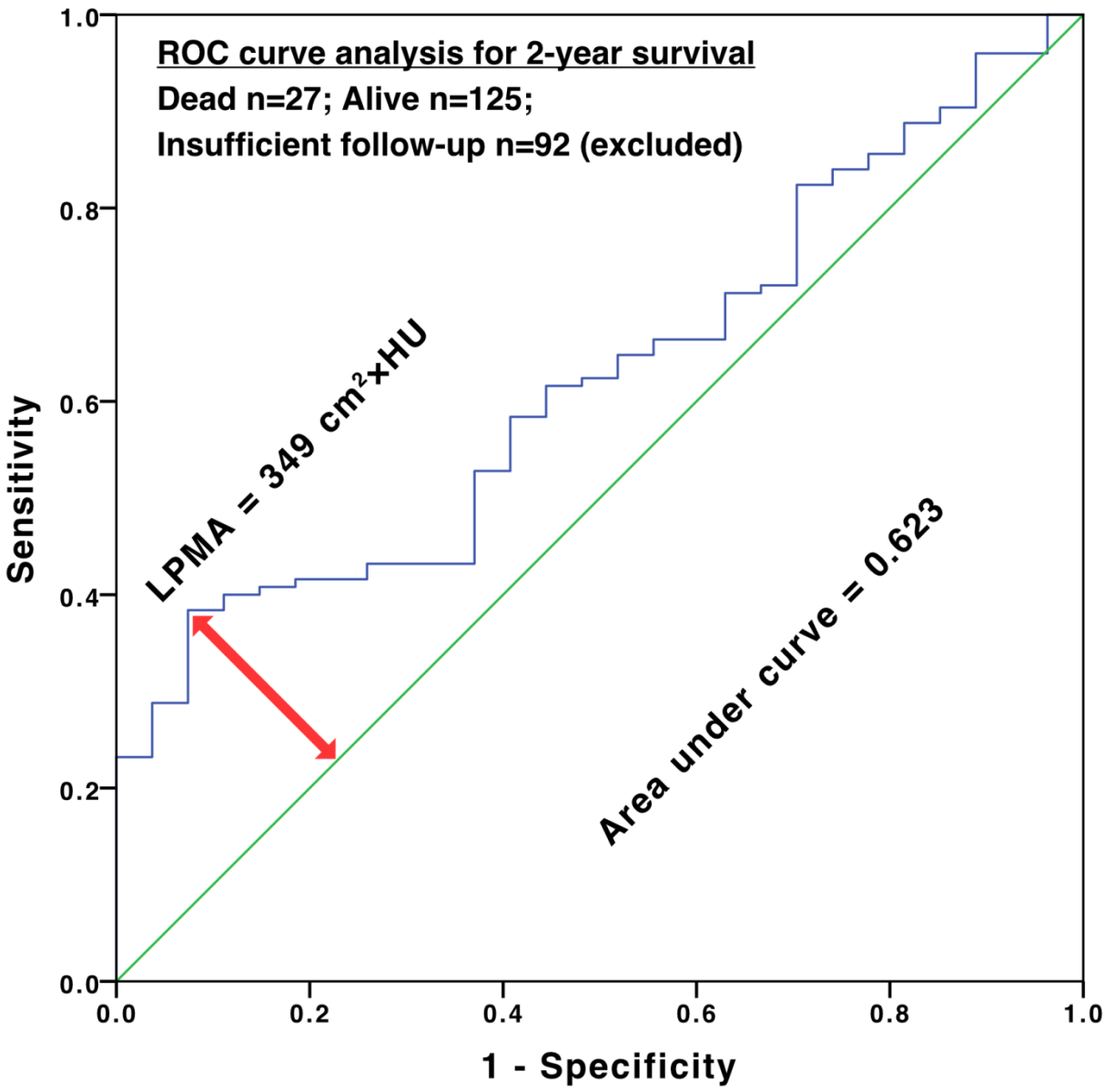
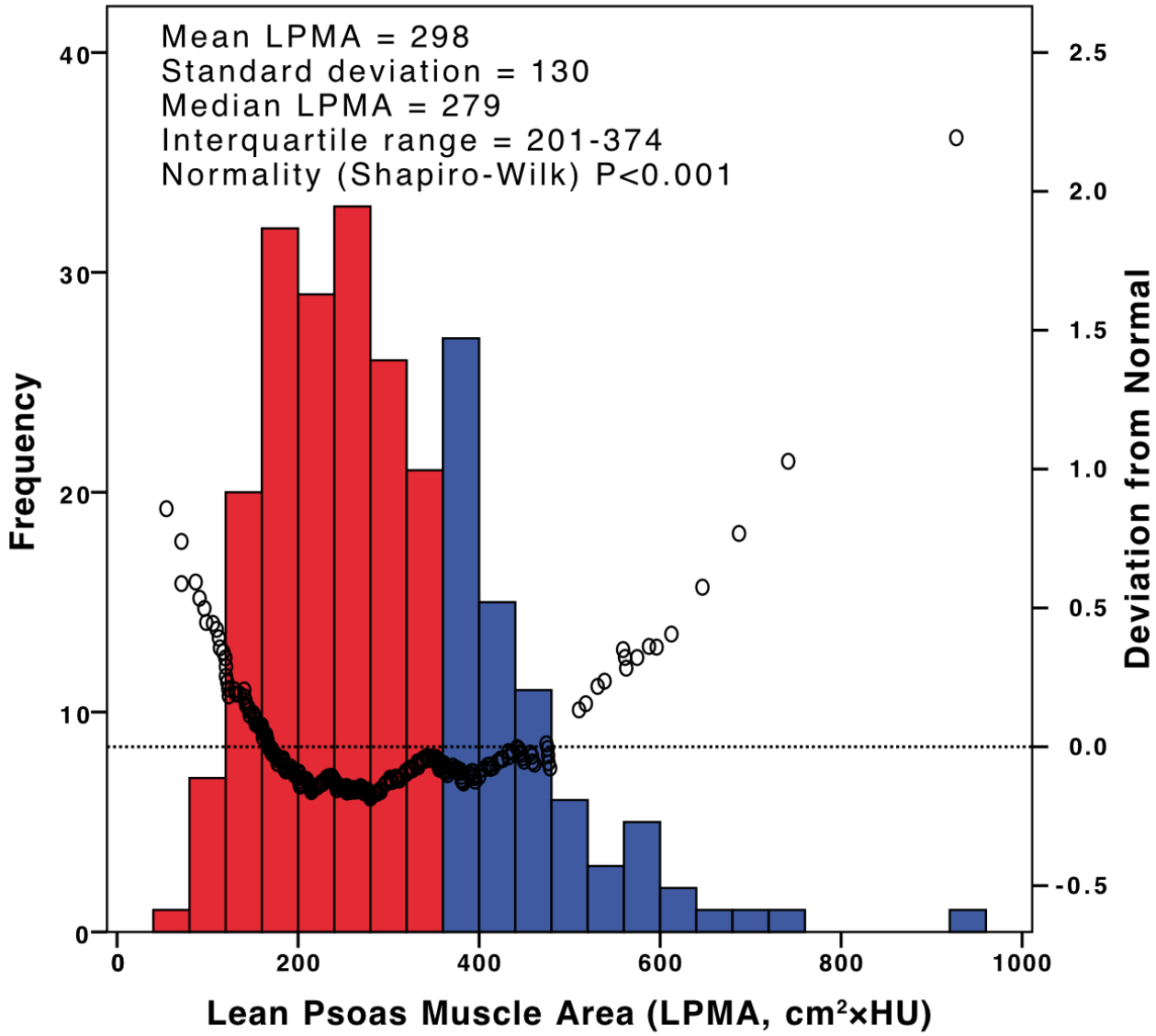


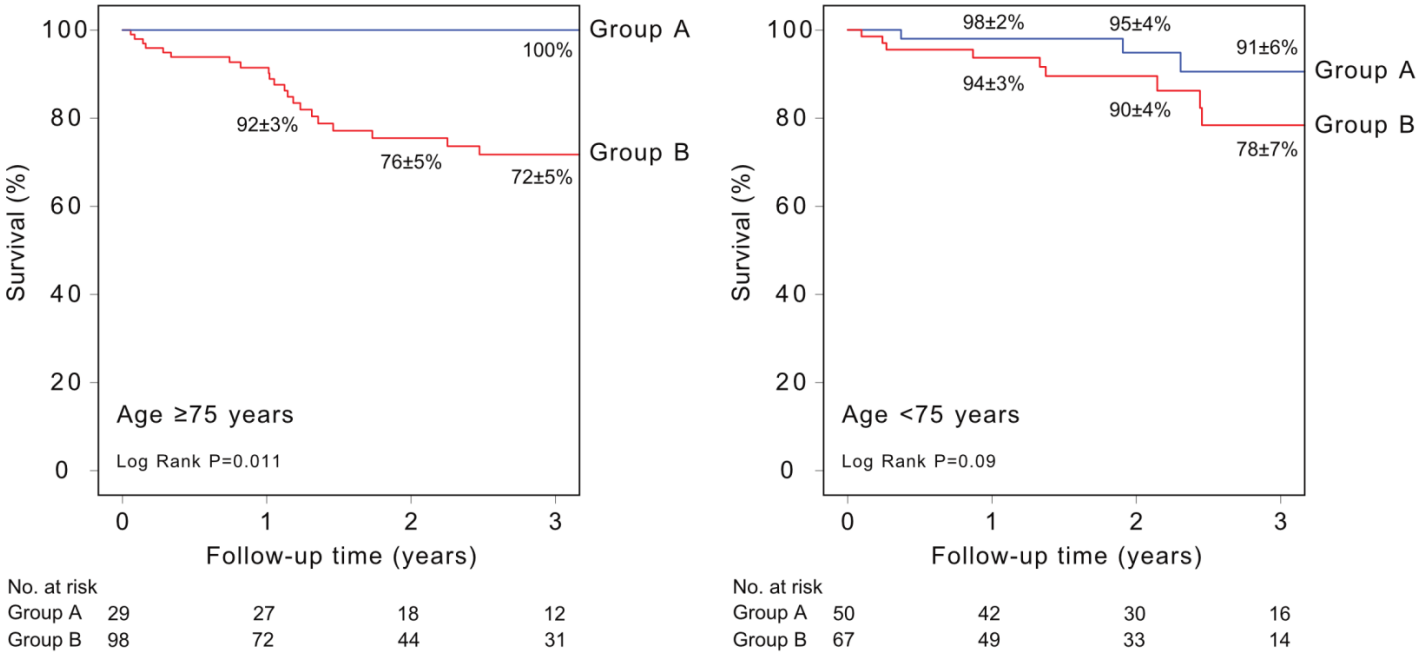
Figure 4. The mean SF-36 quality of life scores in eight subscales at baseline and 12-months. The scores were significantly higher in group A patients at 11 of the 16 subscale and time points.



Supplementary Figure 1. A fixed end point (2-year survival) was used for receiver operator characteristics (ROC) analysis to estimate an optimal cut point for lean psoas muscle area (LPMA); the cut point was defined as the corresponding test value where the distance between the ROC curve and the diagonal reference line was the highest (red arrow). The cut point for LPMA was approximated at 350 cm^2×HU, and the feasibility of this cut point was confirmed in adjusted Cox hazard model (**Figure 2**).



Supplementary Figure 2. The distribution pattern of lean psoas muscle area (LPMA) in 244 study patients. Blue columns = group A patients with high muscle mass (n=79, 32%); red columns = group B patients with low muscle mass (n=165, 68%).



Supplementary Figure 3. Left; 3-year Kaplan-Meier survival estimates for patients aged 75 years or older. Right; survival estimates for patients aged less than 75 years. Group A had LPMA ≥350 cm^2×HU, whereas group B had LPMA <350 cm^2×HU.