# Psoas muscle area and quality are independent predictors of survival in patients treated for abdominal aortic aneurysms

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**ABSTRACT**

**Background:** Sarcopenia is associated with mortality after abdominal aortic aneurysm (AAA) repair. The reliability of computed tomography (CT) core muscle areas and quality i.e. densities and their association with postoperative survival in patients undergoing AAA treatment were retrospectively studied.

**Methods:** Psoas and multifidus areas (PMA, MFA) and densities (PMD, MFD) were measured from CT images and analysed to lean values. Results were standardized by z-scoring. Measurement reliability was ascertained using intraclass correlation coefficient (ICC) analysis (three independent observers). Clinical data was collected from an institutional database and the hospital's patient record database.

**Results:** The study included 301 patients (89% male, mean age 74.4 years, endovascular treatment 73.1%, rupture 7.6%). Median duration of follow-up was 2.70 (IQR 3.54) years and mortality 31.2%. Age, female gender, and BMI were associated with PMA, PMD and lean psoas muscle area (LPMA). L3 left PMD, total psoas muscle density (TPMD), right and left LPMA, lean total psoas muscle area (LTPMA) and L2 right LPMA and LTPMA (HR 0.74-0.78 per one standard deviation, P<.05 – P<.01) were independently associated with improved survival in multivariable analysis.

**Conclusions:** L2-L3 PMD and LPMA are reliable, feasible and independent predictors of mortality in patients treated for AAA. For every standard deviation increase in these standardized z-score muscle parameters, there was a 22% - 26% decrease in the probability of death during follow-up.

**Keywords:** Abdominal Aortic Aneurysm, CT volumetry, Paraspinal muscle

## INTRODUCTION

Surgical procedures for abdominal aortic aneurysms (AAA) are high-risk interventions with considerable postoperative mortality. Survival is influenced by several factors such as urgency of operation, age, sex, and comorbidities like renal insufficiency, congestive heart failure, and chronic obstructive pulmonary disease.[1–5] The effect of treatment modality, open versus endovascular aortic repair (EVAR), has been somewhat controversial but EVAR has shown early survival benefit over open surgery in elective surgery and better long-term survival, cost-effectiveness and quality of life when treating ruptured aneurysms in the emergency setting.[6–12] Development of surgical and anaesthesiologic techniques along with aging of the population has led to vascular surgical patient material becoming more challenging which in turn emphasises the need for improved methods of risk prediction in order to optimise patient safety, operative results, and cost-effectiveness.

Frailty, the age-associated decline in overall physiologic reserve and function, is associated with subclinical cardiovascular disease and appears to be superior to conventional anaesthesiologic or surgical risk scores in estimating postoperative survival.[13–16] Muscle mass measures are one way of assessing frailty and skeletal muscle depletion referred to as sarcopenia has been demonstrated as an independent predictor of postoperative mortality.[16–21] Core muscle mass estimates have been found to be associated with postoperative survival even in patients undergoing elective AAA repair and sarcopenia has been noted to be associated with worse survival after elective EVAR and open surgery.[22–26] The methods for estimating both frailty and sarcopenia vary and the current challenge lies in defining an approach that is objective, reproducible, and convenient for the clinician without adding costs.[13,16] Furthermore, there is a need for evidence on the effect of sarcopenia as an indicator of muscle quality on survival of AAA patients undergoing invasive treatment including also urgent and emergency cases. Psoas muscle area (PMA) can be applied as a quantitative method of estimating core muscle mass and sarcopenia and it correlates with postoperative complications and mortality.[23,27] It should be noted, that PMA correlates negatively with age and positively with weight.[23] Similarly,

paraspinal muscle area has been used in core muscle evaluation and is associated with postoperative survival.[28,29] Taken together, previous evidence on the effect of sarcopenia on survival of AAA patients is limited to elective patients and on PMA while data on reproducibility of the measurement, the value of other muscles and muscle quality as reflected by density is not available.

The purpose of this study was, firstly, to ascertain the reproducibility of core muscle area and quality i.e. density measurement from computed tomography (CT) scans of AAA patients by three independent observers and select the most consistent parameters. Secondly, the study sought to determine the association of sarcopenia represented by these density and lean area parameters with postoperative mortality in a cohort of patients treated for AAA with open surgery or EVAR electively or in an urgent or emergency setting. To explore more clinical association between psoas area and quality we performed muscle parameters standardization by z-scoring.

## METHODS

### Patients

For this study a total of 301 patients were randomly selected from a larger cohort of patients (n=959) undergoing AAA treatment in the Tampere University Hospital (TAUH) vascular clinic between 2001 and 2014. The data was collected from a prospectively constructed institutional database and TAUH patient record database. The clinic's protocol of preoperative assessment entailed aortic imaging with contrast-enhanced CT for each patient. Additional CT imaging was conducted postoperatively as part of the follow-up at one month and two years in patients who underwent EVAR. The treatment modality, open or endovascular surgery, was selected by the treating vascular surgeon often in collaboration with an interventional radiologist in a multidisciplinary meeting. The study adhered to the ethical principles of the Declaration of Helsinki and was approved by Pirkanmaa Hospital District Science Center Approval. Due to the nature of the study no informed patient consent was required or obtained. A total of 100 patients were first evaluated and it was found that a 6-10% change in parameter values caused a significant difference in mortality. It was therefore decided to measure 201 additional patients yielding a sufficient sample. Patients without available CT imaging of the abdominal area between 90 days before and 30 days after the operation with 0.63-3.00 mm slice thickness were excluded. The excluded patients had less dyslipidaemia (28.9 % vs. 43.9%, P<.001) and coronary artery disease (CAD) (41.5 % vs. 50,8 %, P=0.007), but no significant differences were observed in other demographic parameters.

### Imaging parameters

CT scans were obtained using two different multidetector scanners: General Electric LightSpeed 16-row (GE Healthcare, Milwaukee, WI, USA) and Philips Brilliance 64-row (Philips, Cleveland, OH, USA). Scanners were in equal use and patients were not selected to a certain scanner. Abdominal aortic CT imaging was performed using the following parameters: 120 kV, 250 mAs, collimation 64 × 0.625 mm (64-row) or 120 kV, Auto MA (150-350 mAs), collimation 16 × 1.25 mm (16-row).

Contiguous slices were reconstructed to the thickness of 1-3 mm in the whole scanning range. The contrast agent (Xenetix 350 mgI/mL, Aulnay-sous-Bois, France) was administered through an antecubital 18-G cannula using a double-piston power injector with a flow rate of 3 mL/s using 100 mL of contrast agent followed by a 40-mL saline flush. Real-time bolus tracking was used and the acquisition was triggered when the contrast agent opacified the full diameter of the thoracoabdominal aorta. The acquisition was performed during deep-inspiration breath-hold.

**Image analysis, variables, and measurements**

The CT images were reviewed using dedicated medical imaging workstations (Carestream Vue PACS viewer version 11.4.0.1253, Rochester, NY, USA). Density and area measurements were performed from contrast-enhanced arterial phase images and axial slices of 0.63-3.00 mm thickness were used. The distances between the transverse processes were measured from sagittal reformats reconstructed with the multiplanar reformat (MPR) feature of the viewer software. Preferentially, the preoperative aortic imaging study was utilised. When preoperative images with the desired slice thickness were unavailable the one-month or earlier follow-up aortic CT was evaluated (21.9% of cases). Of these, 90.9% were elective and 95.5% were EVAR.

A test sample of 27 patients was first randomly selected and evaluated independently by three clinicians: a radiologist (10 years of experience), a vascular surgeon (15 years of experience), and a junior doctor who had been previously given appropriate instructions. The purpose was to extensively test the reliability and prognostic value of repeated measurement of the same muscle area in the clinical work. All evaluators were blinded to the patients' outcome and test patients' characteristics did not significantly differ from the remaining patients. The remaining patients were evaluated by a single interpreter based on observations from the test sample. The measurements were performed on both sides at four vertebral levels: L2, L3, L4, and L5. A representative axial slice for each vertebral level was chosen at the level of origin of the transverse processes. Regions of interest (ROIs) that separately outlined the psoas and multifidus muscles on both sides were carefully drawn with a free-

hand tool that subsequently produced a report giving the cross-sectional area outlined by the ROI and the mean density in Hounsfield Units (HUs) along with standard deviation (SD) (Figures 1, 2). The idea was to isolate the muscle according to the anatomical boundaries in axial images. Free-hand selection of ROI measured the area and mean density.

Total muscle areas were formed by adding the right and left muscle areas and total muscle densities were calculated as means on each sides at the same vertebral level. Distances between vertebrae were measured between the caudal margins of the transverse processes in the sagittal plane of the mid part of the transverse process of the more cranial vertebra. The side with longer distance was chosen for measurements if there was a visible difference. After confirmation of reproducibility which ranged from fair to excellent being fair in two type of CT measurements, the remaining 274 patients were evaluated by a single interpreter based on the observations gathered from the test sample. Density thresholds for tissue characterizations were set as follows: 20-80 HU normal muscle, 1-19 HU lower density muscle, 0 HU water, -1 to -29 HU fatty muscle, and -30 to -50 HU fatty connective tissue. Contrast between psoas muscle tissue and adipose tissue is considerable as a consequence of prominent fascia and muscle measurements can be done as a semi-automated procedure. Isolation using HU-based segmentation would not work in a muscle with fatty streaks and subfascial fat because the region growing algorithm would not be able to discriminate the intramuscular fat from the surrounding fat. Inside the free-hand ROI, HU-based segmentation into fat and muscle would be possible. However, the density-area product was elected in line with previous reports.[23,29]

Lean muscle area was estimated by the product of total muscle area with average density ($cm^2$ x HU). This value was scored as zero if the average density was below 0 HU. Lean muscle area was estimated by the product of total muscle area with average density ($cm^2$ x HU) which enabled accounting for both muscle area and density on the same variable. Lean muscle area was scored as zero if the average density was below 0 HU. The study centre's medical imaging workstation was not able to directly measure lean variables. The psoas muscle volume was modelled for calculations as a 3D truncated

cone, where distance between vertebrae was the height of the cone and total muscle area was the area of the base of the cone.

**Statistical analysis**

The statistical software used for analyses was SPSS 24 for Mac OS X. Intraclass correlation coefficient analysis (ICC) was applied to ascertain reliability, i.e. interobserver variability of the parameters (areas, densities and distances) measured by the three independent observers. Not all the observers traced the region of interest twice so intraobserver variables are not shown. The two-way random single measurement model was selected and both consistency and absolute agreement were calculated along with 95% confidence intervals.[30] ICC was rated as poor (<0.40), fair (0.40-0.59), good (0.60-0.74) or excellent (0.75-1.00). A test sample size of approximately 10% of the whole sample (>20 patients) is typical in testing the functionality of a study as the measurement error decreases significantly at this threshold. In the present study, post-hoc statistical power estimates were calculated for the ICC values as assurance probabilities as proposed by Zou et al.[31] The assurance probability is alternative to power analysis when ICC results are the primary outcome and it indicates the probability that the lower limit of the confidence interval is no less than the obtained value. In the present study, assurance probabilities results were excellent (0.80-0.92) in almost all of the statistically significant measurements indicating that the 27-patient test sample applied was sufficient.

The distributions of the measured variables were visualised using histograms and analysed for normality using Levene's test. Predictors of survival were analysed using Cox regression first in univariable analyses and testing the proportional hazards assumption by log-minus-log plots, and consequently in a multivariable model including parameters with P<.1 in univariable analysis as covariates. Muscle parameters were entered as continuous variables to the Cox regression analysis. Multivariable regression was adjusted as covariates for age, ruptured AAA, smoking, previous stroke or transient ischemic attack (TIA), creatinine-level, ASA-score, statin and anticoagulant medication.

Multivariable analyses were also calculated by standardized z-scoring variables and analyses were adjusted for the same variables. Statistical significance was set at $P<.05$.

## RESULTS

### Patient demographics

The final study population consisted of 301 patients treated for AAA in TAUH between 2001 and 2014. The demographic data, risk factors, procedural variables, and medication are presented in Table 1. There were no patients with missing data. The majority of patients were male, presented with coronary artery disease (CAD) and hypertension, underwent an elective procedure, received EVAR, were classified as ASA3, and had statin medication.

### Reproducibility of the CT measurements

The distance between L2 and L3 vertebrae was clearly the most consistently measured one among the different vertebral levels based on ICC analysis (consistency 0.599, 95% Cl 0.25-0.86; absolute agreement 0.588, 95% CI 0.25-0.85; Table 2). Thus, muscle volume and density measurements were performed on these two levels. The measurements demonstrated fair to excellent reliabilities, mostly in the range of good reproducibility (Table 2). Consistency was 0.535-0.686 and absolute agreement 0.446-0.585 for PMA at L2, and 0.672-0.720 and 0.640-0.676 at L3, respectively. For PMD consistency was 0.769-0.816 and absolute agreement 0.776-0.793 at L2 level and 0.691-0.765 and 0.693-0.778, correspondingly, at L3 level. PMAs measured at these levels had moderate to high correlation to the areas of the multifidus muscles at the same levels based on Pearson R (L2: R=0.719, P<.01, L3: R=0.469, P<.05). A similar finding was observed when densities were compared (L2: R=0.512, P<.01, L3: R=0.654, P<.01).

### Association of age, gender, and BMI with the CT-measurements

Clinical features were similar between men and women in terms of demographics, risk factors and procedural variables, but men used significantly more antihypertensive medication (P=.04). When comparing sides (dx vs. sin), the left-sided parameters were significantly higher: L2 PMA (5.2 ± 2.0 vs. 5.5 ± 1.9 $cm^2$), L2 PMD (29.3 ± 12.6 vs. 31.7 ± 11.8 HU), L3 PMA (8.2 ± 2.6 vs. 8.5 ± 2.5 $cm^2$),

L3 PMD (32.0 ± 12.0 vs. 33.4 ± 11.3 HU), L2 lean PMA (155.2 ± 93.1 vs. 175.4 ± 93.1 $cm^2$ x HU), L3 lean PMA (253.3 ± 138.2 vs. 287.8 ± 135.9 $cm^2$ x HU) showed significant differences (P<.01 for all).

Table 3 presents the actual median values of measured muscle areas and densities. Furthermore, the effects of age, gender, and BMI are presented on the measured CT parameters. Aging had an overall inverse effect on psoas muscle area, density, lean area and volume, and lean volume. Female gender was associated with decreased psoas muscle area, lean area, density and volume, and lean volume. Finally, BMI was associated with increased psoas muscle area and volume (Table 3).

**Association of CT measurements with mortality**

The follow-up lasted until April 2015 with the median duration of follow-up being 2.70 (IQR 3.54) years. Ninety-four (31.2%) patients died and none were lost during follow-up. Parameters with a tendency to predict survival in univariable analyses (Supplementary table 1) were checked by log-minus-log plots to confirm proportional hazards assumption and were thereafter incorporated into the multivariable analysis (Supplementary table 2). Results were also confirmed by further adjusting the multivariable model with BMI and gender known to associate with PMA and the results remained the same (Supplementary table 3). To explore more clinical association between psoas muscle density or lean area and outcome, the multivariable analysis after muscle parameters standardization by z-scoring was performed (Table 4). L3 left side PMD and total psoas muscle density (TMPD), L3 right and left lean psoas muscle area (LPMA), L3 lean total psoas muscle area (LTPMA) and L2 right LPMA and LTPMA (HR 0.74-0.78 per 10 HU) per one standard deviation (P<.05 – P<.0.01) were independently associated with improved survival in multivariable analysis. The most effective muscle parameter was L3 LTPMA, for which for every standard deviation increase means 26% decrease in the probability of death during follow-up. Z-scoring decreased muscle parameters skewing compared to authentic muscle parameters (Supplementary table 2). Further adjustment of the model with operative approach (EVAR vs. open repair) or urgency (emergency vs. elective) did not have any

effect on the results. Furthermore, multivariable analysis was performed also with z-scored muscle parameters and after exclusion of ruptured AAA-patients. In these analyses, L3 TPMD (HR 0.68-1.01) and L2 LTPMA (HR 0.60-1.01) demonstrated slightly decreased significance, but the most consistently associated muscle parameter L3 LTPMA strengthened and every standard deviation increase was associated with a 29% decrease in the probability of death. Ruptured AAA-patients did not have statistically significant to the results. The effect of pre-postoperative imaging was also tested by univariable Cox regression analysis and no association with survival was found.

## DISCUSSION

Muscle size and quality are significant predictors of postoperative mortality. However, the optimal method for estimating these in a reliable and convenient way is yet to be determined and the evidence regarding vascular surgical patients remains limited. The present study demonstrated the association of muscle quality with mortality in patients treated for AAA in 1-5-year follow-up using PMD, PMA, and lean PMA at the level of the L2 and L3 vertebrae as markers that can be reliably and swiftly measured from CT scans. In the present study, the strongest cut off-value affecting prognosis was a one standard deviation increase in the psoas muscle lean area bilaterally at the L3 level. Specifically, at a cut-off value for total psoas lean area of 269.4 $cm^2$ or greater at the L3 level was associated with a 26% decrease in the probability of death during follow-up. Results can be generalized in the clinical work, when the muscle standardized deviation of the local patient series is measured and known. Other research has studied the association between muscle area and patient outcome, but in the present study, attention was paid also to lean values including both muscle area and density ($cm^2$ x HU). Preoperative CT images within 90 days before the operation were preferred, but if these were unavailable the one-month or earlier postoperative images were used. It was verified that the timing of CT imaging was not significantly associated with survival. It was additionally ascertained that PMD is negatively associated with age and female gender in patients undergoing AAA repair.

The fair to excellent reproducibility of PMA and PMD measurements at L2-L3 vertebral levels as shown by ICC analysis is in line with previous studies and suggests that these parameters can be reproducibly estimated from routine preoperative CT scans.[32,33] PMA and PMD correlated with MFA and MFD at L2-L3 levels. Reproducibility of multifidus muscles areas were tested by ICC at the same vertebral level, but the results were weaker. These findings most likely result from the challenges of outlining the ROIs of the multifidus muscles if there is no perceptible fascia. Apart from left lean muscle volumes the study patients presented with greater muscle areas and densities on the left side compared to the right. Previously, PMA has been found to be greater on the dominant side in a study

cohort of healthy males.[34] A study investigating the potential causes of paraspinal muscle asymmetry in men found only some inconsistent associations with muscle laterality, including handedness.[35] Whether the asymmetry noted in the present study was influenced by the AAA via different mechanisms remains to be elucidated. With regards to factors associated with the investigated muscle parameters, the significant inverse association of age with PMA and PMD fits well to the very definition of frailty and further supports the use of muscle mass and quality estimates as methods of frailty assessment.[13,14,23,36] The tendency of women towards lower PMA, PMD, and lean muscle volume compared to men is supported by preceding evidence.[37–39] The present study found that in addition to age, BMI is associated with increased PMA and total psoas muscle area, which is seconded by current literature.[23] A similar correlation has been noted before in lung cancer patients undergoing pneumonectomy.[21] The multivariable models were adjusted with age, gender, BMI, operative approach and urgency, and with all significant factors found in univariable analyses but these adjustments had no effect on the association of psoas muscle parameters with survival which further confirms the independent role of these parameters as predictors of mortality.

Previous work on the effect of sarcopenia on survival in vascular surgical patients includes a study by Canvasser et al[29], which stated that paraspinal muscle area at Th12 level measured from preoperative abdominal CT scans is associated with postoperative 1 year mortality. Paraspinal muscle area measurements were used as the group found them more easily attainable from routine imaging compared to psoas muscle measurements for a larger group of surgical patients. Additionally, paraspinal muscle area was noted to correlate well with total psoas muscle area at L4 level. Despite the substantial study cohort (n=1309) the percentage of vascular surgical patients was only 13.5, the study excluded outpatients and those subjected to emergency surgeries, and did not provide data on AAA patients. In comparison, the study cohort in the present study is more homogenous entailing only patients subjected to AAA repair, includes both elective and emergency cases, patient data is comprehensive, and the follow-up is longer (2.70 years, IQR 3.54). Previous studies in AAA patients have a comparable follow-up and are in line with the present findings thus consolidating evidence on

the predictive value of PMA in postoperative survival of elective patients (n=149) treated mainly with EVAR (85%; HR 0.86 per $cm^2$)[23], elective patients (n=137) treated mainly with EVAR (96%)[26] and elective patients (n=262) treated with open repair[22]. In more recent papers, Newton et al[24] found sarcopenia to be associated with worse survival in patients (n=135) undergoing elective EVAR (OR 3.9, P=0.027) and Thurston et al[25] presented similar findings in an elective all male EVAR cohort (JR 2.37, P=0.011). Shah et al[26] included postoperative CT images within 3 months after operation in case of missing preoperative images in 12% of cases and the group discovered reduced left PMA at L4 level to be independently associated with mortality which is supported by the results of the present study.[26] Contrary to other works Indrakusuma et al[40] did not find an association between low PMA at the level of L3 and survival in AAA patient. The study of 228 elective, asymptomatic infrarenal AAA patients only 124 underwent AAA repair and 62% of 124 patients were treated by EVAR. Their study did not include patients who had symptomatic pain or ruptured AAA and multivariable analysis of significant univariable parameters and overall survival was not presented. Advantageously, the present study adds on previous knowledge by providing data on the value of PMD and lean PMA parameters, indicating that in addition to area, also muscle quality has predictive value. Furthermore, the present study applied both authentic and z-scored values to control for skewing and to enhance more clinical importance to the results. Low muscle size and density are potential variables when considering the fitness of a patient for operation, particularly for A high risk operation.

The results presented in this paper should be interpreted in the context of a single-centre retrospective study. The vascular registry used is, however, constructed prospectively and annually audited. Furthermore, patients treated before 2005 were mainly excluded from the study since CT slice thickness of 1-3 mm was not routinely used in this centre before 2005, possibly causing patient selection. The one-month or earlier follow-up aortic CT was used in 21.9% of cases and it is unlikely that a significant change in muscle mass or quality would have developed during that time. Furthermore, the timing of the imaging was not found to be associated with survival in a Cox regression analysis. The timing and volume of the contrast agent, and the haemodynamic state of the

patient may have influenced the density measurements. Densities measured in small patients with hyperkinetic circulation may be overestimated compared to large patients with slow circulation**.** Another likely yet small contributor to selection bias may have been that in rare cases of unstable patients requiring immediate intervention, the decision to operate was made based solely on ultrasound without concomitant CT imaging. The strengths of the present study lie in a large and homogenous patient cohort comprising elective and urgent or emergency cases and patients treated with open surgery and EVAR, structural collection of data, and a noticeable follow-up time.

## CONCLUSION

L2 – L3 PMD and LPMA offer a valuable adjunct to postoperative risk prediction in patients treated for AAA and they can be reliably and swiftly measured without added costs. At strongest, this means that for every standard deviation increased from psoas muscle lean value bilaterally at L3 level there is a 26% decrease in the probability of death during follow-up. In clinical use PMD and LPMA standardized z-scoring help to perceive prognosis when standard deviation is known.

## CONFLICTS OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the contents and writing of the paper.

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**REFERENCES**


1 Thompson SG, Ashton HA, Gao L, Buxton MJ, Scott RAP. Final follow-up of the Multicentre Aneurysm Screening Study (MASS) randomized trial of abdominal aortic aneurysm screening. *Br J Surg* 2012;**99**(12):1649–56. Doi: 10.1002/bjs.8897.

2 Beck AW, Goodney PP, Nolan BW, Likosky DS, Eldrup-Jorgensen J, Cronenwett JL. Predicting 1-year mortality after elective abdominal aortic aneurysm repair. *J Vasc Surg* 2009;**49**(4):838–44. Doi: 10.1016/j.jvs.2008.10.067.

3 Grootenboer N, van Sambeek MRHM, Arends LR, Hendriks JM, Hunink MGM, Bosch JL. Systematic review and meta-analysis of sex differences in outcome after intervention for abdominal aortic aneurysm. *Br J Surg* 2010;**97**(8):1169–79. Doi: 10.1002/bjs.7134.

4 Mureebe L, Egorova N, McKinsey J, Kent K. Gender trends in the repair of ruptured abdominal aortic aneurysms and outcomes. *J Vasc Surg* 2010;**51**:9S–13S.

5 Schlosser FJ, Vaartjes I, van der Heijden GJ, Moll FL, Verhagen HJ MB et al. Mortality after elective abdominal aortic aneurysm repair. *Ann Surg* 2010;**251**:158–64.

6 Greenhalgh R, Brown L, Kwong G, Powell J, Thompson S. Comparison of endovascular aneurysm repair with open repair in patients with abdominal aortic aneurysm (EVAR trial 1), 30-day operative mortality results: randomised controlled trial. *Lancet* 2004;**364**:843–8. Doi: 10.1016/S0140-6736(04)16979-1.

7 Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D SM. Endovascular versus Open Repair of Abdominal Aortic Aneurysm. *N Engl J Med* 2010;**362**(20):2645–54. Doi: 10.1056/NEJMoa1608029.

8 Lederle FA, Freischlag JA KT et al. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: A randomized trial. *JAMA* 2009;**302**(14):1535–42.

9 Powell JT, Sweeting MJ, Thompson MM, Ashleigh R, Bell R, Gomes M, et al. Endovascular or open repair strategy for ruptured abdominal aortic aneurysm: 30 day

outcomes from IMPROVE randomised trial. *BMJ* 2014;**348**(January):1–12. Doi: 10.1136/bmj.f7661.

10 Prinssen M, Verhoeven EL, Buth J, Cuypers PW, van Sambeek MR BR et al. A Randomized Trial Comparing Conventional and Endovascular Repair of Abdominal Aortic Aneurysms. *N Engl J Med* 2004;**351**(16):1607–18. Doi: 10.1056/NEJMoa1608029.

11 Patel R, Sweeting MJ, Powell JT, Greenhalgh RM. Endovascular versus open repair of abdominal aortic aneurysm in 15-years' follow-up of the UK endovascular aneurysm repair trial 1 (EVAR trial 1): a randomised controlled trial. *Lancet* 2016;**388**(10058):2366–74. Doi: 10.1016/S0140-6736(16)31135-7.

12 Investigators IT. Comparative clinical effectiveness and cost effectiveness of endovascular strategy v open repair for ruptured abdominal aortic aneurysm: three year results of the IMPROVE randomised trial. *Bmj* 2017;(359):j4859. Doi: 10.1136/bmj.j4859.

13 Keevil VL, Romero-Ortuno R. Ageing well: A review of sarcopenia and frailty. *Proc Nutr Soc* 2015;**74**(4):337–47. Doi: 10.1017/S0029665115002037.

14 Chikwe J, Adams DH. Frailty: The Missing Element in Predicting Operative Mortality. *Semin Thorac Cardiovasc Surg* 2010;**22**(2):109–10. Doi: 10.1053/j.semtcvs.2010.09.001.

15 Newman AB, Gottdiener JS, McBurnie MA, Hirsch CH, Kop WJ, Tracy R, et al. Associations of subclinical cardiovascular disease with frailty.[see comment]. *Journals Gerontol Ser A-Biological Sci Med Sci* 2001;**56**(3):M158-66.

16 Afilalo J, Alexander KP, Mack MJ, Maurer MS, Green P, Allen LA, et al. Frailty assessment in the cardiovascular care of older adults. *J Am Coll Cardiol* 2014;**63**(8):747–62. Doi: 10.1016/j.jacc.2013.09.070.

17 Cesari M, Leeuwenburgh C, Lauretani F, Onder G, Bandinelli S MC et al. Frailty syndrome and skeletal muscle: results from the Invecchiare in Chianti study. *Am J Clin*

*Nutr* 2006;**83**(5):1142–8. Doi: 10.1016/j.fertnstert.2010.09.017.Development.

18 Englesbe MJ, Patel SP, He K, Lynch RJ, Schaubel DE HC et al. Sarcopenia and post-liver transplant mortality. *J Am Coll Surg* 2010;**211**(2):271–8. Doi: 10.1016/j.jamcollsurg.2010.03.039.Sarcopenia.

19 Kaido T, Ogawa K, Fujimoto Y, Ogura Y, Hata K, Ito T, et al. Impact of Sarcopenia on Survival in Patients Undergoing Living Donor Liver Transplantation. *Am J Transpl* 2013;**13**:1549–56. Doi: 10.1002/ajt.12221.

20 Masuda T, Shirabe K, Ikegami T, Harimoto N, Yoshizumi T SY et al. Sarcopenia Is a Prognostic Factor in Living Donor Liver Transplantation. *Liver Transplant* 2014;**20**:401–7. Doi: 10.1002/lt.

21 Hervochon R, Bobbio A, Guinet C, Mansuet-Lupo A, Rabbat A, Regnard J-F, et al. Body Mass Index and Total Psoas Area Affect Outcomes In Patients Undergoing Pneumonectomy for Cancer. *Ann Thorac Surg* 2016;**103**:287–95. Doi: 10.1016/j.athoracsur.2016.06.077.

22 Lee JS-J, He K, Harbaugh CM, Schaubel DE, Sonnenday CJ, Wang SC, et al. Frailty, core muscle size, and mortality in patients undergoing open abdominal aortic aneurysm repair. *J Vasc Surg* 2011;**53**(4):912–7. Doi: 10.1016/j.jvs.2010.10.111.

23 Drudi LM, Phung K, Ades M, Zuckerman J, Mullie L, Steinmetz OK, et al. Psoas Muscle Area Predicts All-Cause Mortality After Endovascular and Open Aortic Aneurysm Repair. *Eur J Vasc Endovasc Surg* 2016;**52**(6):764–9. Doi: 10.1016/j.ejvs.2016.09.011.

24 Newton DH, Kim C, Lee N, Wolfe L, Pfeifer J, Amendola M. Sarcopenia predicts poor long-term survival in patients undergoing endovascular aortic aneurysm repair. *J Vasc Surg* 2018;**67**(2):453–9. Doi: 10.1016/j.jvs.2017.06.092.

25 Thurston B, Pena GN, Howell S, Cowled P, Fitridge R. Low total psoas area as scored in the clinic setting independently predicts midterm mortality after endovascular aneurysm repair in male patients. *J Vasc Surg* 2018;**67**(2):460–7. Doi:

10.1016/j.jvs.2017.06.085.

26 Shah N, Abeysundara L, Dutta P, Christodoulidou M, Wylie S, Richards T, et al. The association of abdominal muscle with outcomes after scheduled abdominal aortic aneurysm repair. *Anaesthesia* 2017:1107–11. Doi: 10.1111/anae.13980.

27 Jones KI, Doleman B, Scott S, Lund JN, Williams JP. Simple psoas cross-sectional area measurement is a quick and easy method to assess sarcopenia and predicts major surgical complications. *Color Dis* 2015;**17**(1):O20–6. Doi: 10.1111/codi.12805.

28 Bouche KG, Vanovermeire O, Stevens VK, Coorevits PL, Caemaert JJ, Cambier DC, et al. Computed tomographic analysis of the quality of trunk muscles in asymptomatic and symptomatic lumbar discectomy patients. *BMC Musculoskelet Disord* 2011;**12**(1):65. Doi: 10.1186/1471-2474-12-65.

29 Canvasser LD, Mazurek AA, Cron DC, Terjimanian MN, Chang ET, Lee CS, et al. Paraspinous muscle as a predictor of surgical outcome. *J Surg Res* 2014;**192**(1):76–81. Doi: 10.1016/j.jss.2014.05.057.

30 Wolak ME, Fairbairn DJ, Paulsen YR. Guidelines for estimating repeatability. *Methods Ecol Evol* 2012;**3**(1):129–37. Doi: 10.1111/j.2041-210X.2011.00125.x.

31 Zou GY. Sample size formulas for estimating intraclass correlation coefficients with precision and assurance. *Stat Med* 2012;**31**(29):3972–81. Doi: 10.1002/sim.5466.

32 Sinelnikov A, Qu C, Fetzer DT, Pelletier JS, Dunn MA, Tsung A, et al. Measurement of skeletal muscle area: Comparison of CT and MR imaging. *Eur J Radiol* 2016;**85**(10):1716–21. Doi: 10.1016/j.ejrad.2016.07.006.

33 Hu ZJ, He J, Zhao FD, Fang XQ ZL et al. An assessment of the intra- and inter-reliability of the lumbar paraspinal muscle parameters using CT scan and magnetic resonance imaging. *Spine (Phila Pa 1976)* 2011;**36**:E868-74.

34 Stewart S, Stanton W, Wilson S, Hides J. Consistency in size and asymmetry of the psoas major muscle among elite footballers. *Br J Sports Med* 2010;**44**(16):1173–7. Doi: 10.1136/bjsm.2009.058909.

35 Fortin M, Yuan Y, Battie MC. Composition in a General Population Sample of Men. *Phys Ther* 2013;**93**(11):1540–50.

36 Kalyani RR, Corriere M, Ferrucci L. Age-related and disease-related muscle loss: The effect of diabetes, obesity, and other diseases. *Lancet Diabetes Endocrinol* 2014;**2**(10):819–29. Doi: 10.1016/S2213-8587(14)70034-8.

37 Marras WS, Jorgensen MJ, Granata KP, Wiand B. Female and male trunk geometry: Size and prediction of the spine loading trunk muscles derived from MRI. *Clin Biomech* 2001;**16**(1):38–46. Doi: 10.1016/S0268-0033(00)00046-2.

38 Luckenbaugh AN, Hollenbeck BK, Montgomery JS, Lee CT, Gilbert SM, Dunn RL, et al. Using Analytic Morphomics to Understand Short-Term Convalescence after Radical Cystectomy. *Bl Cancer* 2016;**2**:235–40. Doi: 10.3233/BLC-150045.

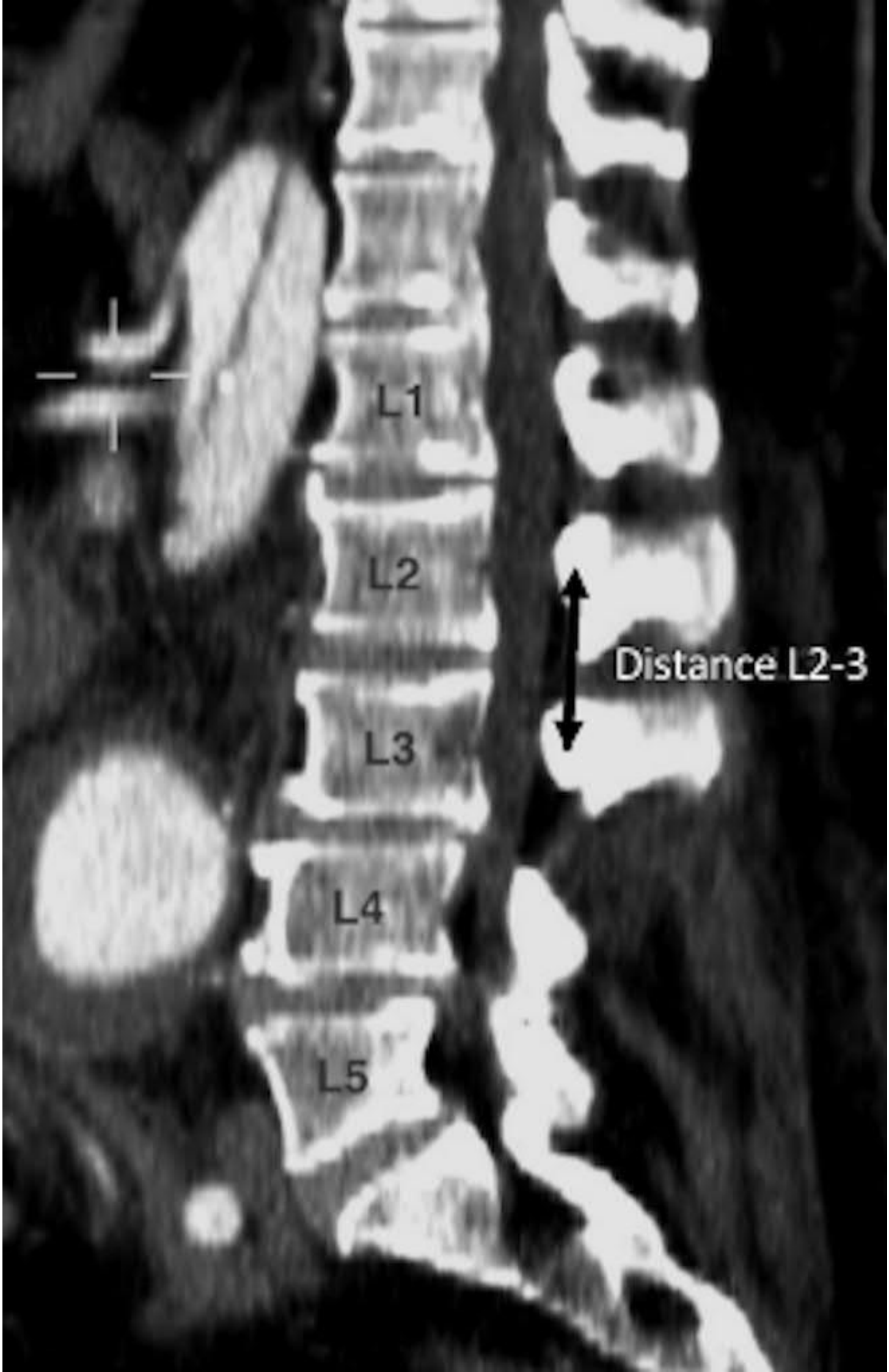
39 Janssen I, Heymsfield SB, Wang Z, Ross R, Kung TA, Cederna PS, et al. Skeletal muscle mass and distribution in 468 men and women aged 18 − 88 yr Skeletal muscle mass and distribution in 468 men and women aged 18 – 88 yr. *J Appl Physiol* 2000;**89**:81–8.

40 Indrakusuma R, Zijlmans JL, Jalalzadeh H, Planken RN, Balm R, Koelemay MJW. Psoas Muscle Area as a Prognostic Factor for Survival in Patients with an Asymptomatic Infrarenal Abdominal Aortic Aneurysm: A Retrospective Cohort Study. *Eur J Vasc Endovasc Surg* 2018;**55**(1):83–91. Doi: 10.1016/j.ejvs.2017.10.007.

## LEGENDS FOR ILLUSTRATIONS

**Fig.1** Muscle measurement. Outlining the region of interest (ROI): Psoas (and multifidus) muscles on both sides. Area was measured in $mm^2$. RPMA; right psoas muscle area, LPMA; left psoas muscle area, RMMA; right multifidus muscle area, LMMA; left multifidus muscle area.

**Fig.2** Illustration of the measurement used for this study between vertebrae L2 and L3. Estimating gaps between spinal discs on transverse processes from bottom of the more cranial vertebra.


L1
L2
L3
L4
L5
Distance L2-3


RPMA
LPMA
RMMA
LMMA

Table 1. Patient demographics and risk factors.

| Features | Sample N=301 |
|---|---|
| Demographics | |
| Age (years) | 74.4 ± 9.4 |
| Male (%) | 268 (89%) |
| Height (m) | 1.76 ± .08 |
| BMI (kg/m2) | 26.6 ± 4.4 |
| Risk factors | |
| Previous intervention | 20 (6.6%) |
| Smoking | 71 (23.6%) |
| CAD | 158 (50.8%) |
| DM | 41 (13.6%) |
| HTA | 192 (63.8%) |
| Dyslipidemia | 132 (43.9%) |
| Pulmonary disease | 68 (22.6%) |
| Stroke or TIA | 34 (11.3%) |
| Creatinine level (µmol/l) | 86 ± 83 |
| Procedural variables | |
| rAAA | 23 (7.6%) |
| OR | 81 (26.9%) |
| EVAR | 220 (73.1%) |
| ASA 2 | 16 (5.3%) |
| ASA 3 | 176 (58.5%) |
| ASA 4 | 92 (30.6%) |
| ASA 5 | 17 (5.6%) |

| | |
|---|---|
| Medication | |
| Antiaggregant | 148 (49.2%) |
| Anticoagulant | 72 (23.9%) |
| Oral antidiabetic | 26 (8.6%) |
| Insulin | 19 (6.3%) |
| Beta blocker | 179 (59.5%) |
| Other antihypertensive | 184 (61.1%) |
| Statin | 168 (55.8%) |
| Glucocorticoid | 19 (6.3%) |

CAD, Coronary artery disease; DM, Diabetes mellitus; HTA, Hypertensio arterialis; TIA, transient ischaemic attack; rAAA, ruptured abdominal aortic aneurysm; OR, open repair of abdominal aortic aneurysm; EVAR, endovascular repair of abdominal aortic aneurysm; ASA, American Society for Anaesthesiologists classification.

Table 2. Intraclass correlation coefficient (ICC) analysis of CT-measurements.

| Variable | | | ICC[a] | 95% CI | ICC[b] | 95% CI | P-value |
|---|---|---|---|---|---|---|---|
| L2 | | | | | | | |
| | dx psoas m. | Area | .686 | .36-.89 | .585 | .21-.85 | < .001 |
| | | HU | .816 | .58-.94 | .793 | .54-.93 | < .001 |
| | sin psoas m. | Area | .535 | .17-.83 | .446 | .10-.77 | .002 |
| | | HU | .769 | .50-.92 | .776 | .51-.93 | < .001 |
| | dx multifidus m. | Area | -.113 | -.34-0.29 | -.036 | -.10-0.14 | .758 |
| | | HU | .705 | .40-.90 | .675 | .36-.89 | < .001 |
| | sin multifidus m. | Area | -.117 | -.34-0.31 | -.051 | -.15-0.20 | .726 |
| | | HU | .690 | .37-.89 | .698 | .39-.90 | < .001 |
| L3 | | | | | | | |
| | dx psoas m. | Area | .674 | .35-.89 | .640 | .31-.87 | < .001 |
| | | HU | .765 | .49-.92 | .778 | .52-.93 | < .001 |
| | sin psoas m. | Area | .720 | .42-.91 | .676 | .35-.89 | < .001 |
| | | HU | .691 | .37-.89 | .693 | .38-.89 | < .001 |
| | dx multifidus m. | Area | .175 | -.16-0.61 | .076 | -.06-0.38 | .167 |
| | | HU | .823 | .59-.94 | .818 | .59-.94 | < .001 |
| | sin multifidus m. | Area | -.055 | -.30-0.39 | -.019 | -.10-0.19 | .595 |
| | | HU | .814 | .58-.94 | .804 | .57-.94 | < .001 |
| L4 | | | | | | | |
| | dx psoas m. | Area | .812 | .57-.94 | .740 | .40-.92 | < .001 |
| | | HU | -.036 | -.29 – 0.41 | -.036 | -.30 – 0.41 | .553 |
| | sin psoas m. | Area | .028 | -.25-0.48 | .027 | -.24-0.46 | .416 |
| | | HU | .772 | .50-.93 | .786 | .52-.93 | < .001 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | dx multifidus m. | Area | .050 | -.24-0.50 | .046 | -.21-0.47 | .372 |
| | | HU | .811 | .57-.94 | .801 | .56-.94 | < .001 |
| | sin multifidus m. | Area | .199 | -.14-0.62 | .185 | -.12-0.60 | .138 |
| | | HU | .843 | .63-.95 | .849 | .65-.95 | < .001 |
| L5 | | | | | | | |
| | dx psoas m. | Area | .916 | .79-.97 | .862 | .57-.96 | < .001 |
| | | HU | .784 | .52-.93 | .766 | .50-.92 | < .001 |
| | sin psoas m. | Area | .351 | -.02-0.73 | .350 | -.01-0.72 | .032 |
| | | HU | .798 | .55-.94 | .811 | .57-.94 | < .001 |
| | dx multifidus m. | Area | .757 | .48-.92 | .653 | .26-.88 | < .001 |
| | | HU | .719 | .42-.91 | .736 | .44-.91 | < .001 |
| | sin multifidus m. | Area | .756 | .48-.92 | .756 | .48-.92 | < .001 |
| | | HU | .716 | .41-.90 | .719 | .42-.91 | < .001 |
| L2-L3 Distance | | | .599 | .25-.86 | .588 | .25-.85 | .001 |
| L3-L4 Distance | | | .257 | -.10-0.66 | .268 | -.10-0.68 | .084 |
| L4-L5 Distance | | | .310 | -.05-0.70 | .287 | -.04-0.68 | .050 |

[a] Model: Intraclass correlation coefficient (ICC) two-way random consistency.

[b] Model: Intraclass correlation coefficient (ICC) two-way random absolute.

dx, dexter; sin, sinister; HU, Hounsfield unit.

Table 3. The effect of age, gender and BMI on CT-measurements and the actual medians.

| | Age | | | Gender | | BMI | | | Median | SD |
|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | M | F | T1 | T2 | T3 | | |
| | 65.1 | 74.4 | 82.4 | | | 22.9 | 26.0 | 31.1 | | |
| Distance between L2-L3 (cm) | 34.8 | 34.0 | **33.6[a]** | 34.5 | 31.2 | 34.3 | 34.3 | 34.3 | 34.3 | 3.2 |
| L2 | | | | | | | | | | |
| dx PMA ($cm^2$) | 5.8 | 4.9 | **4.3[a]** | 5.2 | 3.0 | 4.2 | 4.8 | **5.6[c]** | 4.9 | 2.0 |
| dx PMD (HU) | 33.5 | 28.0 | **24.0[a]** | 30.0 | **22.0[b]** | 33.0 | 28.0 | 29.0 | 30.0 | 12.6 |
| dx lean PMA ($cm^2$ x HU) | 187.6 | 147.4 | **109.8[a]** | 154.4 | 68.9 | 134.3 | 148.0 | 158.4 | 147.8 | 93.1 |
| sin PMA ($cm^2$) | 6.0 | 5.5 | **4.6[a]** | 5.6 | 3.6 | 4.7 | 5.5 | **6.0[c]** | 5.5 | 1.9 |
| sin PMD (HU) | 37.0 | 30.0 | **31.0[a]** | 32.0 | 28.0 | 34.5 | 30.0 | 31.0 | 31.0 | 11.8 |
| sin lean PMA ($cm^2$ x HU) | 207.6 | 166.4 | **147.4[a]** | 182.8 | 114.2 | 169.6 | 166.6 | 178.4 | 170.3 | 93.1 |
| TPMA ($cm^2$) | 11.7 | 10.7 | **8.9[a]** | 10.9 | 6.9 | 8.9 | 10.6 | **11.6[c]** | 10.6 | 3.6 |
| TPMD (HU) | 34.8 | 29.0 | **27.3[a]** | 31.3 | 28.0 | 32.8 | 29.5 | 29.5 | 30.5 | 11.3 |
| Lean TPMA ($cm^2$ x HU) | 388.3 | 309.2 | **254.4[a]** | 330.7 | **451.0[b]** | 294.8 | 309.5 | 329.1 | 314.0 | 177.1 |
| L3 | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| dx PMA ($cm^2$) | 9.1 | 8.0 | **7.1**[a] | 8.1 | 5.1 | 6.9 | 8.1 | **9.1**[c] | 7.9 | 2.6 |
| dx PMD (HU) | 37.0 | 32.0 | **29.0**[a] | 33.0 | **28.0**[b] | 34.5 | 33.0 | 32.0 | 33.0 | 12.0 |
| dx lean PMA ($cm^2$ x HU) | 310.1 | 242.4 | **187.8**[a] | 266.2 | **121.8**[b] | 221.6 | 257.3 | 260.0 | 253.5 | 138.2 |
| sin PMA ($cm^2$) | 9.5 | 8.2 | **7.6**[a] | 8.6 | **5.4**[b] | 7.5 | 8.5 | **9.5**[c] | 8.3 | 2.4 |
| sin PMD (HU) | 38.0 | 33.0 | **32.0**[a] | 35.0 | 33.0 | 37.0 | 34.0 | 33.0 | 34.0 | 11.3 |
| sin lean PMA ($cm^2$ x HU) | 344.5 | 280.0 | **225.4**[a] | 301.2 | **157.7**[b] | 266.6 | 280.2 | 301.2 | 282.0 | 135.9 |
| TPMA ($cm^2$) | 18.5 | 16.3 | **14.6**[a] | 16.8 | **11.0**[b] | 14.5 | 16.5 | **18.5**[c] | 16.3 | 4.9 |
| TPMD (HU) | 37.3 | 32.5 | **29.5**[a] | 33.5 | 29.0 | 34.8 | 32.5 | 33.0 | 33.0 | 10.8 |
| Lean TPMA ($cm^2$ x HU) | 653.4 | 522.2 | **414.2**[a] | 556.5 | **768.3**[b] | 523.3 | 540.6 | 548.4 | 532.1 | 262.7 |
| | | | | | | | | | | |
| Right psoas volume ($cm^3$) | 26.3 | 22.2 | **18.5**[a] | 23.0 | **12.8**[b] | 19.0 | 22.5 | **25.0**[c] | 21.8 | 8.2 |
| Lean volume ($cm^3$ x HU) | 849.3 | 701.7 | **491.5**[a] | 715.4 | **338.1**[b] | 617.3 | 706.7 | 707.8 | 684.8 | 402.6 |
| Left psoas volume ($cm^3$) | 25.9 | 23.7 | **20.9**[a] | 24.4 | **13.7**[b] | 20.5 | 23.9 | **26.2**[c] | 23.7 | 7.8 |
| Lean volume ($cm^3$ x HU) | 933.8 | 7765.9 | **622.6**[a] | 824.0 | 423.9 | 748.1 | 760.1 | 843.8 | 785.8 | 398.6 |
| Total psoas volume ($cm^3$) | 52.0 | 45.9 | **40.0**[a] | 47.2 | **26.9**[b] | 39.7 | 45.8 | **50.5**[c] | 45.5 | 15.6 |
| Lean total volume ($cm^3$ x HU) | 1770.0 | 1514.4 | **1141.7**[a] | 1566.9 | **747.3**[b] | 1428.4 | 1505.2 | 1577.0 | 1495.2 | 769.0 |

Values presented are medians. T, tertile; M, male; F, female; PMA, psoas muscle area; PMD, psoas muscle density; TPMA, total (sin and dx) psoas muscle area; TPMD, total psoas muscle density; HU, density in Hounsfield units; BMI, body mass index; sin, sinister; dx, dexter; SD, standard deviation. Volumes have been calculated between L2 and L3 vertebrae. [a] The oldest tertile has statistically significant difference compared to the youngest tertile (P<.05, One-way Anova or Kruskal-Wallis test). [b] Females have statistically significant difference compared to males (P<.05, independent-samples T-test or chi-squared test). [c] The highest tertile has statistically significant difference compared to the lowest tertile (P<.05, One-way Anova or Kruskal-Wallis test).

Table 4. Multivariable cox regression analysis of overall survival

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | | Model 6 | | Model 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl |
| Age | **1.06[c]** | **1.03-1.09** | **1.06[c]** | **1.03-1.09** | **1.06[c]** | **1.03-1.09** | **1.06[c]** | **1.03-1.09** | **1.05[c]** | **1.03-1.09** | **1.05[c]** | **1.02-1.09** | **1.05[c]** | **1.02-1.08** |
| rAAA | **5.07[c]** | **2.17-11.84** | **5.04[c]** | **2.15-11.81** | **5.16[c]** | **2.21-12.01** | **4.82[c]** | **2.10-11.10** | **4.91[c]** | **2.14-11.29** | **4.78[c]** | **2.09-10.92** | **4.91[c]** | **2.14-11.26** |
| Smoking | 1.09 | 0.62-1.92 | 1.12 | 0.64-1.98 | 1.07 | 0.61-1.89 | 1.06 | 0.60-1.88 | 1.07 | 0.61-1.89 | 1.02 | 0.58-1.80 | 1.05 | 0.60-1.84 |
| Stroke or TIA | 1.82 | 1.00-3.30 | **1.83[a]** | **1.00-3.34** | 1.76 | 0.97-3.19 | 1.75 | 0.96-3.17 | 1.77 | 0.97-3.22 | 1.81 | 0.99-3.28 | 1.80 | 0.99-3.26 |
| Creatinine | **1.03[c]** | **1.02-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.02-1.05** | **1.03[c]** | **1.01-1.05** |
| ASA | 1.11 | 0.76-1.61 | 1.12 | 0.77-1.62 | 1.16 | 0.81-1.67 | 1.17 | 0.81-1.68 | 1.15 | 0.80-1.66 | 1.13 | 0.79-1.63 | 1.14 | 0.79-1.64 |
| Medication | | | | | | | | | | | | | | |
| Anticoagulant | 1.13 | 0.71-1.81 | 1.12 | 0.70-1.79 | 1.08 | 0.68-1.73 | 1.10 | 0.69-1.76 | 1.11 | 0.70-1.78 | 1.11 | 0.70-1.78 | 1.11 | 0.70-1.77 |
| Statin | 0.67 | 0.44-1.03 | 0.67 | 0.44-1.02 | **0.66[a]** | **.43-1.00** | 0.66 | 0.43-1.00 | 0.66 | 0.43-1.02 | 0.66 | 0.43-1.01 | 0.67 | 0.44-1.02 |
| CT parameter z-score | | | | | | | | | | | | | | |
| *L3 sin PMD* | **0.76[b]** | **0.63-0.93** | | - | | - | | - | | - | | - | | - |
| *L3 TPMD* | | - | **0.78[a]** | **0.64-0.95** | | - | | - | | - | | - | | - |
| *L2 dx LPMA* | | - | | - | **0.78[a]** | **0.61-0.99** | | - | | - | | - | | - |
| *L2 LTPMA* | | - | | - | | - | **0.78[a]** | **0.61-1.00** | | - | | - | | - |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *L3 dx LPMA* | - | - | - | - | **0.76[a]** | **0.60-0.95** | - | | - | |
| *L3 sin LPMA* | - | - | - | - | - | | **0.75[a]** | **0.59-0.94** | - | |
| *L3 LTPMA* | - | - | - | - | - | | - | | **0.74[a]** | **0.58-0.93** |

PMA, psoas muscle area; PMD, psoas muscle density; TPMD, total psoas muscle density; TPMA, total (sin and dx) psoas muscle area; LPMA, lean psoas muscle area; LTPMA, lean total psoas muscle area; rAAA, ruptured abdominal aortic aneurysm; TIA, transient ischaemic attack; ASA, American Society for Anesthesiologists classification; sin, sinister; dx, dexter. Creatinine level and HU-values are transformed to 1/10 values. The effect of area and volume parameters is presented as per $cm^2$ and $cm^3$, respectively. Hazard ratio (HR) estimated from Cox hazard regression model. Confidence interval (CI) of the estimated HR. [a] Indicates significant difference $P<.05$, [b] $P<.01$ and [c] $P<.001$.

**Psoas muscle area and quality are independent predictors of survival in patients treated for abdominal aortic aneurysms**

Annals of Vascular Surgery

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Supplementary table 1. Univariable cox regression analysis of overall mortality.

| Risk factor | HR | 95% Cl |
|---|---|---|
| **Age** | **1.06[c]** | **1.04-1.09** |
| Gender | 1.05 | 0.56-1.98 |
| Height | 1.00 | 0.97-1.02 |
| BMI | 0.97 | 0.92-1.02 |
| **rAAA** | **3.25** | **1.76-6.00** |
| Previous operation | 1.05 | 0.43-2.60 |
| **Smoking** | **0.64[a]** | **0.38-1.09** |
| CAD | 1.31 | 0.87-1.97 |
| DM | 1.31 | 0.74-2.31 |
| HTA | 0.92 | 0.61-1.39 |
| Dyslipidemia | 0.70 | 0.46-1.07 |
| Pulmonal disease | 0.95 | 0.58-1.55 |
| **Stroke or TIA** | **1.79[b]** | **1.01-3.18** |
| **Creatine level** | **1.00[c]** | **1.00-1.01** |
| EVAR | 1.28 | 0.79-2.07 |
| **ASA** | **1.70[c]** | **1.26-2.29** |
| Medication | | |
| Antiaggregant | 1.08 | 0.72-1.62 |
| **Anticoagulant** | **1.50[a]** | **0.96-2.34** |
| Oral antidiabetic | 0.96 | 0.45-2.09 |
| Insulin | 0.80 | 0.32-1.96 |
| Beta blocker | 1.04 | 0.69-1.57 |

| | | |
|---|---|---|
| Other antihypertensive | 1.06 | 0.70-1.60 |
| **Statin** | **0.61[b]** | **0.41-0.92** |
| Glucocorticoid | 1.76 | 0.85-3.66 |

BMI, Body mass index; rAAA, ruptured abdominal aortic aneurysm; CAD, Coronary artery disease; DM, Diabetes mellitus; HTA, Hypertensio arterialis; TIA, transient ischaemic attack; EVAR, Endovascular aortic repair; ASA, American Society for Anaesthesiologists Classification. Hazard ratio (HR) estimated from Cox hazard regression model. Confidence interval (CI) of the estimated HR. Variables demonstrating significant associations with mortality on univariate analysis (P< .1) were incorporated into multivariate analysis. [a] indicates significant difference P<.1, [b]P<.05 and [c]P<.01.

**Psoas muscle area and quality are independent predictors of survival in patients treated for abdominal aortic aneurysms**

Annals of Vascular Surgery

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Supplemenatry table 2. Multivariable cox regression analysis of standardized z-scoring

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | | Model 6 | | Model 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl |
| Age | **1.06[c]** | **1.03-1.09** | **1.06[c]** | **1.03-1.09** | **1.06[c]** | **1.03-1.09** | **1.06[c]** | **1.03-1.09** | **1.05[c]** | **1.03-1.09** | **1.05[c]** | **1.02-1.09** | **1.05[c]** | **1.02-1.08** |
| rAAA | **5.07[c]** | **2.17-11.84** | **5.04[c]** | **2.15-11.81** | **5.16[c]** | **2.21-12.01** | **4.82[c]** | **2.10-11.10** | **4.91[c]** | **2.14-11.29** | **4.78[c]** | **2.09-10.92** | **4.91[c]** | **2.14-11.26** |
| Smoking | 1.09 | 0.62-1.92 | 1.12 | 0.64-1.98 | 1.07 | 0.61-1.89 | 1.06 | 0.60-1.88 | 1.07 | 0.61-1.89 | 1.02 | 0.58-1.80 | 1.05 | 0.60-1.84 |
| Stroke or TIA | 1.82 | 1.00-3.30 | **1.83[a]** | **1.00-3.34** | 1.76 | 0.97-3.19 | 1.75 | 0.96-3.17 | 1.77 | 0.97-3.22 | 1.81 | 0.99-3.28 | 1.80 | 0.99-3.26 |
| Creatinine | **1.03[c]** | **1.02-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.01-1.05** | **1.03[c]** | **1.02-1.05** | **1.03[c]** | **1.01-1.05** |
| ASA | 1.11 | 0.76-1.61 | 1.12 | 0.77-1.62 | 1.16 | 0.81-1.67 | 1.17 | 0.81-1.68 | 1.15 | 0.80-1.66 | 1.13 | 0.79-1.63 | 1.14 | 0.79-1.64 |
| Medication | | | | | | | | | | | | | | |
| Anticoagulant | 1.13 | 0.71-1.81 | 1.12 | 0.70-1.79 | 1.08 | 0.68-1.73 | 1.10 | 0.69-1.76 | 1.11 | 0.70-1.78 | 1.11 | 0.70-1.78 | 1.11 | 0.70-1.77 |
| Statin | 0.67 | 0.44-1.03 | 0.67 | 0.44-1.02 | **0.66[a]** | **.43-1.00** | 0.66 | 0.43-1.00 | 0.66 | 0.43-1.02 | 0.66 | 0.43-1.01 | 0.67 | 0.44-1.02 |
| CT parameter | | | | | | | | | | | | | | |
| *L3 sin PMD* | **0.79[b]** | **0.66-0.94** | | - | | - | | - | | - | | - | | - |
| *L3 TPMD* | | - | **0.80[a]** | **0.66-0.96** | | - | | - | | - | | - | | - |
| *L2 dx LPMA* | | - | | - | **0.97[a]** | **0.95-1.00** | | - | | - | | - | | - |
| *L2 LTPMA* | | - | | - | | - | **0.99[a]** | **0.97-1.00** | | - | | - | | - |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *L3 dx LPMA* | - | | - | | - | | - | | **0.98[a]** | **0.96-1.00** | - | - |
| *L3 sin LPMA* | - | | - | | - | | - | | - | | **0.98[a]** | **0.96-1.00** | - | - |
| *L3 LTPMA* | - | | - | | - | | - | | - | | - | | **0.99[a]** | **0.98-1.00** |
| CT parameter z-score | | | | | | | | | | | | |
| *L3 sin PMD* | **0.76[b]** | **0.63-0.93** | - | | - | | - | | - | | - | | - | |
| *L3 TPMD* | - | | **0.78[a]** | **0.64-0.95** | - | | - | | - | | - | | - | |
| *L2 dx LPMA* | - | | - | | **0.78[a]** | **0.61-0.99** | - | | - | | - | | - | |
| *L2 LTPMA* | - | | - | | - | | **0.78[a]** | **0.61-1.00** | - | | - | | - | |
| *L3 dx LPMA* | - | | - | | - | | - | | **0.76[a]** | **0.60-0.95** | - | | - | |
| *L3 sin LPMA* | - | | - | | - | | - | | - | | **0.75[a]** | **0.59-0.94** | - | |
| *L3 LTPMA* | - | | - | | - | | - | | - | | - | | **0.74[a]** | **0.58-0.93** |

PMA, psoas muscle area; PMD, psoas muscle density; TPMD, total psoas muscle density; TPMA, total (sin and dx) psoas muscle area; LPMA, lean psoas muscle area; LTPMA, lean total psoas muscle area; rAAA, ruptured abdominal aortic aneurysm; TIA, transient ischaemic attack; ASA, American Society for Anesthesiologists classification; sin, sinister; dx, dexter. Creatinine level and HU-values are transformed to 1/10 values. The effect of area and volume

parameters is presented as per $cm^2$ and $cm^3$, respectively. Hazard ratio (HR) estimated from Cox hazard regression model. Confidence interval (CI) of the estimated HR. [a] Indicates significant difference $P<.05$, [b] $P<.01$ and [c] $P<.001$.

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Supplementary table 3. Multivariable cox regression analysis of overall mortality.

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | | Model 6 | | Model 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl | HR | 95% Cl |
| Age | **1.06**[c] | 1.03-1.09 | **1.06**[c] | 1.03-1.09 | **1.06**[c] | 1.03-1.09 | **1.06**[c] | 1.03-1.09 | **1.06**[c] | 1.03-1.09 | **1.06**[c] | 1.03-1.09 | **1.06**[c] | 1.03-1.09 |
| Gender | 0.61 | 0.31-1.19 | 0.57 | 0.29-1.12 | **0.47**[a] | 0.23-0.95 | **0.49**[a] | 0.24-0.98 | **0.48**[a] | 0.24-0.96 | **0.43**[b] | 0.21-0.88 | **0.44**[a] | 0.22-0.89 |
| BMI | 0.98 | 0.93-1.03 | 0.98 | 0.93-1.04 | 1.00 | 0.95-1.05 | 1.00 | 0.82-1.05 | 0.99 | 0.94-1.05 | 1.00 | 0.94-1.05 | 0.99 | 0.98-0.99 |
| CT parameter | | | | | | | | | | | | | | |
| *L3 sin PMD* | **0.76**[b] | 0.63-0.91 | | - | | - | | - | | - | | - | | - |
| *L3 TPMD* | | - | **0.76**[b] | 0.63-0.92 | | - | | - | | - | | - | | - |
| *L2 dx LPMA* | | - | | - | **0.96**[b] | 0.94-0.99 | | - | | - | | - | | - |
| *L2 LTPMA* | | - | | - | | - | **0.98**[b] | 0.97-1.00 | | - | | - | | - |
| *L3 dx LPMA* | | - | | - | | - | | - | **0.97**[b] | 0.96-0.99 | | - | | - |
| *L3 sin LPMA* | | - | | - | | - | | - | | - | **0.97**[c] | 0.95-0.99 | | - |
| *L3 LTPMA* | | - | | - | | - | | - | | - | | - | **0.98**[c] | 0.98-0.99 |

PMA, psoas muscle area; PMD, psoas muscle density; TPMD, total psoas muscle density; TPMA, total (sin and dx) psoas muscle area; LPMA, lean psoas muscle area; LTPMA, lean total psoas muscle area; rAAA, ruptured abdominal aortic aneurysm; TIA, transient ischaemic attack;

ASA, American Society for Anesthesiologists classification; sin, sinister; dx, dexter. Creatinine level and HU-values are transformed to 1/10 values. The effect of area and volume parameters is presented as per $cm^2$ and $cm^3$, respectively. Hazard ratio (HR) estimated from Cox hazard regression model. Confidence interval (CI) of the estimated HR. Other covariates included in the model: rAAA, smoking, stroke or TIA, creatinine, ASA, anticoagulant, statin. [a] Indicates significant difference $P<.05$, [b]$P<.01$ and [c]$P<.001$.