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Acute post-traumatic muscle atrophy on CT scan predicts prolonged mechanical ventilation and a worse outcome in severe trauma patients

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Acute post-traumatic muscle atrophy diagnosed on psoas computed tomography scan predicts prolonged mechanical ventilation and a worse outcome in severe trauma patients

ABSTRACT

Background: The aim of present study was to assess the association between acute post-traumatic atrophy (APTMA) determined on psoas computed tomography [CT] scan and the duration of mechanical ventilation and outcomes in severe trauma patients.

Methods: A retrospective analysis of severe trauma patients (Injury Severity Score [ISS], >15) hospitalized in the intensive care unit (ICU) for more than 7 days between January 2010 and December 2015 was performed. The psoas muscle index (PMI) was measured on admission and at delayed CT scan. Δ PMI was calculated as the percentage PMI loss between these two scans. Three groups were defined and compared a posteriori using the quartiles of the Δ PMI values: low (lower quartile), moderate, and severe (higher quartile) APTMA groups. Linear regression analysis was performed to predict the duration of mechanical ventilation, of catecholamines, length of stay (LOS) in the ICU and hospital, and complications were assessed.

Results: A total of 114 trauma patients were included (median age, 40 years; [IQR, 25–54 years]; ISS, 33 [IQR, 25–41]). Based on the Δ PMI determination, 29 patients were allocated in the low APTMA group (range Δ PMI, 0%–6%), 56 in the moderate APTMA group (range Δ PMI, 6%–18%), and 29 in the APTMA group (range Δ PMI, \geq 19%). Severity of APTMA was significantly associated with the duration of mechanical ventilation and catecholamines, ICU and hospital LOS ($P<0.001$). Delayed pneumonia ($P=0.006$) and other delayed infections ($P=0.014$), as well as thromboembolic events ($P=0.04$) were statistically associated with the severity of APTMA, whereas mortality did not differ between the three groups ($P=0.20$). Using linear regression analysis, each Δ PMI increase of 1% was significantly associated with 0.90 supplementary days of mechanical ventilation ($P<0.001$), 0.29 supplementary days of catecholamines ($P<0.001$) and 0.82 supplementary days of hospitalization ($P<0.001$). All these statistical associations were confirmed in multivariate analysis ($P<0.001$).

Conclusion: Acute muscle atrophy diagnosed on CT scan by psoas area measurement (Δ PMI) was strongly associated with poor outcomes in severe trauma patients.

Keywords: Critically ill; Infection; Multiple organ failure; Muscle wasting; Psoas muscle index (PMI); Respiratory complications; Respiratory failure; Sarcopenia

Background

Sarcopenia is defined as loss of muscle mass and muscle strength [1,2]. Muscle strength is strongly associated with poor outcomes in critically ill patients during hospitalization [3–5]. Several authors have therefore proposed that populations at risk could be identified by detecting the presence of sarcopenia using computed tomography (CT) scan measurements. Abdominal CT images focused on the third lumbar vertebral level can provide an objective and easy measurement of the surface of psoas muscle. This simple CT criterion has been well documented as a robust marker of physiologic reserve and a good reflection of total body muscle content [6,7]. In many studies, the area of psoas muscle on CT images has been correlated with poor outcomes in multiple settings, including oncologic or emergent surgery, and liver transplantation [8–12].

In trauma, a few studies demonstrated that sarcopenia in elderly patients, documented on admission CT scan, was also strongly associated with the occurrence of early complications, hospital duration, dependant discharge and mortality [6,13–15]. However, severe trauma patients are commonly young and healthy people, without any comorbid factors. Pre-existing sarcopenia is not often found in this specific population. In contrast, many severe trauma patients have been shown to experience significant and early muscle wasting during the first days after traumatic aggression [16,17]. Many causes may explain this **acute post-traumatic muscle atrophy (APTMA)**, included a hyperinflammatory cascade and neuroendocrine stress response to tissue damage, total immobilization and inappropriate nutrition [1]. However, no studies have investigated the relationship between **APTMA** and poor outcome. Moreover, studies documenting **APTMA** have used unreliable, complex or invasive diagnostic tools, such as spectrometry, indirect calorimetry, or muscle biopsy to document early sarcopenia [18–22]. Applicability of these methods in clinical practice does not seem possible. In contrast, CT scans are commonly used in the early phase of severe trauma management. We have therefore

hypothesized that the objective determination of **APTMA** on successive psoas CT scans can predict delayed complications and poor outcome in severely injured patients.

The aim of present study was to assess the performance of **APTMA**, determined by a decrease in psoas muscle area on CT scans, to predict the duration of mechanical ventilation and worse outcome in a severe trauma population.

Patients and methods

Study design and patients

This retrospective cohort study was performed in the trauma intensive care unit (ICU) of Lapeyronie University Hospital (Regional Level-1 Trauma Centre, Montpellier, France) from January 2010 to December 2015. Patients were included if the length of stay (LOS) in the ICU was >7 days and two consecutive abdominal CT scans were performed (the first on admission and the second between day 5 and day 15). Exclusion criteria were (1) transfer from another hospital; (2) minors (age <18 years); (3) absence of admission or second abdominal CT scan; (4) consistent lack of clinical data; (5) **unstable lumbar spinal fracture with significant distraction**. Patient consent was not considered necessary by our local ethical committee.

Data collection

Anthropometric data, clinical and biological admission parameters and initial management details were obtained from medical records: age, sex, height, weight, body mass index (BMI), type of trauma, haemoglobin level and prothrombin time ratio (PT_r) on admission, initial management and transfusion needs. For each patient, the Injury Severity Score (ISS) and the Abbreviated Injury Scale (AIS) score by body area (head, chest, abdomen, pelvis, and extremity) were determined [23,24]. Severe anatomic injuries were defined by an AIS score ≥ 3 . Daily enteral and parenteral nutritional intakes were also recorded during the ICU stay. Duration

of mechanical ventilation and use of catecholamines, and renal replacement therapy needs were especially documented. Delayed infections after day 7 were also recorded (*i.e.* pneumonia, septicemia, urinary infection, infection at the surgical site and vascular catheter, *Clostridioides difficile* colitis, and invasive candidiasis), as well as thromboembolic events, hospital LOS, and mortality.

CT imaging study

Admission and second CT scans were analysed for the present study by an independent radiologist blinded to patient outcomes. The cross-sectional area of the right psoas muscle was studied using a semi-automated procedure with manual outlining of the muscle borders on an abdominal CT axial cut focused on the third lumbar vertebra (Fig. 1) [25–27]. The density was defined for this measure between –29 and +150 Hounsfield units. The psoas muscle index (PMI) was thus determined for each area measured using the following equation to normalize values according to the patient’s height [28,29]:

$$\text{PMI (mm}^2/\text{m}^2) = \text{right psoas area}/\text{height}^2$$

Subsequently, the change in the PMI between admission and second CT measure (ΔPMI) was calculated for each patient using the following equation:

$$\Delta\text{PMI} = 100 \times (\text{admissionPMI} - \text{secondPMI})/\text{admissionPMI}$$

ΔPMI was expressed as a percentage and zero was attributed if the value was negative.

Statistical analysis

Patients were divided *a posteriori* into three groups using study imaging based on the quartiles of the ΔPMI values: *low APTMA* group (lowest quartile, Q1), *severe APTMA* group (highest quartile, Q4) and *moderate APTMA* group (two intermediate quartiles, Q2 + Q3). These three groups were first compared in terms of the demographic and admission characteristics, as

well as nutritional intakes in the 15 first days of ICU management in order to identify risk statistically associated with the severity of **APTMA**. Average daily global intakes on the first week normalized for weight (kcal/kg/J) were calculated for each patient as the most robust reflection of caloric intakes during this period. The main outcomes (*i.e.* duration of mechanical ventilation, ICU and hospital LOS, occurrence of delayed pneumonia and other delayed infections, thromboembolic events, renal replacement therapy needs and mortality) were then studied to highlight adverse consequences associated with **APTMA**. Continuous data are presented as median values with interquartile range (IQR) and compared using the Kruskal-Wallis test. Categorical variables are expressed as numbers (percentages) and compared using the χ^2 test.

To demonstrate the linearity of the relationship between **APTMA** and outcome parameters, Δ PMI was also analysed as a continuous variable. Linear regression models were built to highlight the strength of the association between the duration of mechanical ventilation and use of catecholamines use, as well as ICU and hospital LOS. The strength of these associations was adjusted by confounding factors using multivariable linear regressions. The following variables *a priori determined* were included in the multivariable analysis: age, BMI, sex, ISS, severe anatomic injuries based on AIS score, white blood cell count on admission, massive transfusion needs (≥ 10 units of packed red blood cells), invasive surgical interventions, average daily global intake in the first week, timing of the second CT scan. The final regression models only conserved significant variables, and the homoscedasticity and distribution of the residuals were confirmed graphically. A *P* value < 0.05 was considered statistically significant. All analyses were performed with XLSTAT 7.5.2 software (Addinsoft, New York, USA).

Results

Study population and baseline characteristics

Among the 1906 trauma patients admitted consecutively to our trauma ICU during the 6-year period, 1792 patients were excluded from the analysis: 347 (19%) admissions from another institution, 536 (30%) with an ISS <16, 758 (42%) early discharges or early deaths, 140 (8%) absences of usable second CT scan, **2 lumbar spinal distractions** and 9 (1%) missing clinical data. Thus, 114 patients were analysed in the present study. The main mechanisms of injury were vehicle collisions, falls, and bicycle-motorcycle crashes. The median age was 40 years (IQR, 25–54 years), median ISS was 33 (IQR, 25–41), 34% presented a severe brain injury, and 26% initially required a massive transfusion. In the study population, 18% of patients had a BMI <18 kg/m², and 23% had a BMI >25 kg/m². The main characteristics of the patients are summarized in Table 1.

Details of daily global and enteral nutritional intakes during the first 3 weeks of management are presented in Fig. 2A. The median calorie intakes was 0 kcal/kg (IQR, 0–6 kcal/kg) on day 2, and 19 kcal/kg (IQR, 12–24 kcal/kg) on day 7 (Fig. 2). The median of the average daily global intakes on the first week was 10 kcal/kg/day (IQR, 6.5–16 kcal/kg/day). Median duration of mechanical ventilation was 11 days (IQR, 5–20 days), whereas median ICU and hospital LOS were 18 days (IQR, 12–31 days) and 29 days (IQR, 19–45 days), respectively. Among the main complications, 67% of patients experienced sepsis, 32% had a thromboembolic event, and 11% required renal replacement therapy. The mortality rate on discharge was 10%.

*Study imaging and **muscle atrophy** determination*

The median admission PMI was 329 mm²/m² (IQR, 257–403 mm²/m²). The median day of the second CT scan was 8 days (IQR, 6–10 days). The median difference between admission

PMI and second PMI was 39 mm²/m² (IQR, 19–63 mm²/m²), leading to a median Δ PMI of 12% (IQR, 6%–19%) (Fig. 3, Table 2).

Based on Δ PMI values, 29 patients were allocated to the *low APTMA* group (range Δ PMI, 0%–6%), 56 patients to the *moderate APTMA* group (range Δ PMI, 6%–18%), and 29 patients to the *severe APTMA* group (range Δ PMI, 19%–55%). These three groups significantly differed in terms of crude and relative values of Δ PMI ($P < 0.001$; Table 2). These three groups differed also in terms of SAPS II score ($P = 0.01$), prevalence of severe pelvic injuries ($P = 0.04$), admission haemoglobin level ($P = 0.04$) and massive transfusion needs ($P = 0.055$; Table 1). In contrast, BMI as well as gender, age, ISS, or other severe injuries did not significantly differ between the groups. The median of average daily global intakes on the first week were paradoxically higher in the *severe APTMA* group ($P = 0.022$) (Fig. 2).

Acute post-traumatic muscle atrophy and outcome

The duration of mechanical ventilation was longer, duration of the need for catecholamines was longer, and the ICU and hospital LOS were longer with increasing severity of *APTMA* ($P < 0.001$). Similarly, the severity of *APTMA* was significantly associated with the risk of pneumonia ($P = 0.006$), other sepsis ($P = 0.014$) and thromboembolic events ($P = 0.041$) (Fig. 4). A trend was also observed for renal replacement therapy requirements ($P = 0.056$) and mortality ($P = 0.20$) (Table 3).

Univariate linear regressions showed that Δ PMI was significantly associated with the duration of mechanical ventilation, duration of catecholamines, and ICU and hospital LOS ($P < 0.001$). After adjustment for confounding variables, each 1% decrease in Δ PMI was associated with 0.78 day (95% confidence interval [CI], 0.61–0.95 day) of mechanical ventilation, 0.23 day (95% CI, 0.13–0.33 day) of catecholamines, 0.91 day (95% CI, 0.66–1.15 day) of ICU LOS and 0.63 day (95% CI, 0.31–0.96 day) of hospital LOS ($P < 0.001$) (Table 4).

Discussion

In this large retrospective series of 114 severe trauma patients (median ISS, 33) hospitalized in our trauma ICU for more than 7 days, we found that **APTMA** was significantly associated with more complications and a poor outcome. Using the classification of *low* (range Δ PMI, 0%–6%), *moderate* (range Δ PMI, 7%–18%) and *severe APTMA* (range Δ PMI, 19%–55%), the severity of **APTMA** was indeed significantly associated with the occurrence of delayed pneumonia ($P=0.006$), other sepsis ($P=0.014$) and thromboembolic events ($P=0.041$), despite similar ISS and trauma severity. Similarly, duration of mechanical ventilation and use catecholamines and hospitalization LOS were significantly longer when Δ PMI was higher ($P<0.001$). These statistical relationships were also confirmed by the linear regression analysis and after adjustment for confounding factors ($P<0.001$). No **significant** risk factor of **APTMA** was revealed by our analysis despite a trend for haemorrhagic status on admission.

Many studies on different populations have previously shown that a low muscle mass documented at admission was predictive of poor prognosis [11,30,31]. A slow and progressive loss of muscle mass during cancer progression was thus proven to be significantly associated with more numerous complications and higher mortality [32–34]. Miyake et al. [35] reported reduced survival and a longer duration of hospitalization after oncologic radical cystectomy when the Δ PMI over 2 months was higher than 10%. In contrast to chronic affections, traumatic aggression induces acute and fast muscle wasting. Many risk factors are similar between chronic sarcopenia and **APTMA**, however the brutality and intensity of the mechanisms that occur after trauma explain this massive muscle wasting. The usual causes of **acute muscle atrophy** induced by trauma are an inflammatory cascade, impaired microcirculation and denervation, endocrine and metabolic alterations, stress hormone production, impaired absorption of nutrients and increased losses. The type of management may also aggravate muscle wasting, such as neuromuscular blocking agents, sedative drugs, prescribed bedrest and inappropriate calories

intakes. All these factors highlight the importance of better understanding of the physiopathological mechanisms of **acute muscle atrophy** in the context of severe trauma, **which may differ from chronic sarcopenia**.

Although sarcopenia has been largely validated as a frailty index and a marker of severity, no detection method seems to date to be reliable and usable in clinical practice. BMI or serum albumin levels have been shown to have many limitations to assess nutritional status [37–39]. Muscle strength scores are only usable in aware and cooperative patients. Absorptiometry tools require a patient transfer, which is challenging to perform in an unstable or ventilated patient. Bioelectrical impedance would seem attractive because it is an inexpensive and rapid measure, but this is known to depend on the hydration status [40]. Furthermore, indirect calorimetry only measures energy expenditure and not muscle mass. Therefore, most of the current methods are inappropriate to diagnose robustly **acute muscle atrophy** in critically ill or unstable patients. An ultrasonographic muscle study was also proposed to assess muscle **loss**, however its reproducibility remains controversial [41]. For all these reasons, CT imaging has progressively become a gold standard for the detection of sarcopenia **or muscle atrophy**. Some authors have indeed proved that muscle size measured by CT scan at the third vertebral level was strongly correlated with total body muscle mass [7,42]. Many studies have also demonstrated a strong correlation with poor outcomes in multiple clinical situations; oncologic or emergent abdominal surgery, liver transplantation, and trauma [9,29,31,43,44]. In these studies, CT scan measurements were focused either on overall lumbar muscles or only psoas muscle. Psoas muscle area measurements, determined by PMI, proved to be well correlated with total body muscle mass [35]. PMI determination is reliable, easier and speedier than complete muscle analysis, therefore we focused our CT imaging study on its evolution.

The present study has studied the decrease in PMI on CT images (Δ PMI) in the days **following a severe traumatic aggression and initial management (median ISS of studied**

population 33). Regarding admission PMI values, our findings confirm that the majority of the severe trauma population does not have pre-existing sarcopenia in contrast with other study populations [8,14,31]. This reveals logically that most phenomena leading to acute muscle atrophy occur rapidly and massively after the trauma, confirming the relevance of Δ PMI assessment during early phase of management. We thus observed that most of our cohort experienced a decrease in PMI on the second scan (median day on day 8); median Δ PMI was indeed 12% over a few days, with extreme values exceeding 30% highlighting the magnitude of early muscle wasting. Relative variations of PMI overexpress probably muscle atrophy phenomenon in patients with a low admission PMI, even if three groups presented a comparable admission PMI. Moreover, the timing of the second CT scan may also be supposed to influence the value of Δ PMI, although this parameter was not found to be significant in the multivariable analysis (Table 4). As expected, the Δ PMI value was not found in our series to be associated with BMI, age or gender. In contrast, a relationship would seem to exist between APTMA severity and several markers of trauma severity or haemorrhagic parameters (Table 1). In addition, immobilization and sedation, well known to generate muscle wasting and global disability, seem to have been more used in severe APTMA group (Table 3). These factors could favour the acute muscle atrophy in post-trauma context. Furthermore, physiological reserve is probably another important determinant of this acute muscle loss, but it could not be apprehended with this retrospective work. Anyway, our analysis found a statistical and gradual association between the severity of APTMA and catecholamine and mechanical ventilation duration, ICU LOS, as well as occurrence of delayed infections and thromboembolic events (Fig. 3 and Table 3). These statistical associations were confirmed after adjustment by confounding factors, such as age, BMI, sex, ISS, severe anatomic injuries based on AIS score, massive transfusion needs, cumulative 7 days nutritional intakes, and the timing of the second CT scan (Table 4). A trend for mortality was also observed, with a probable lack of statistical power ($P=0.20$; Fig. 3). The loss of muscle mass and strength might however have less impact on

mortality in a healthy population than an older one or among those affected by chronic diseases [29].

Our study has **therefore** proved **the** statistical association between **APTMA** assessed on a psoas CT scan and outcome. **Some confusing bias such as initial severity injuries, immobilization or sedation could not however be totally excluded despite multivariable analysis.** Obviously, **this observation** does not affirm whether **APTMA** is the cause of poor outcome or simply a severity marker. Some experts have suggested that skeletal muscle could play an active role in systemic inflammatory triggering, immune response and tissue repair. Skeletal muscle would be indeed able to adapt after stress, producing heat shock proteins, which are protective enzymes against further damage [46]. Heat shock protein serum levels were found to be associated with a higher rate of survival in a series of severe trauma patients [47]. Rapid loss of muscle mass in severely injured patients could thus lead to a reduction in the production of protective protein, favouring organ failure and an impaired prognosis. However, this hypothesis must be confirmed **to be able to evoke a potential causality**. The present analysis supports anyway that determination of **APTMA by Δ PMI value is** easy, objective and reliable. **We** believe that **identifying acute muscle atrophy** in severe trauma patients **when a control CT scan is available could help to determine patients at higher risk of complication and situations that impose optimal calorie intake** [48–51]. A prospective trial will be **however** necessary to confirm the efficiency of such a strategy.

Our study has several limitations that must be considered. First, data obtained from a single institution must be confirmed by external validation. Second, the retrospective design might also introduce potential selection bias, even though the number of patients excluded for lack of data was relatively low. Third, PMI measurements were performed by one only radiologist, and using manual outlining of psoas muscle area. However, previous studies have demonstrated a strong correlation between intra-analyst and inter-analyst observers [12,39].

Moreover, software measurements did not show any difference with manual contouring [52].

Fourth, pre-hospital fluid resuscitation might have increased admission PMI by diffusion and oedema phenomena related to fluid therapy. Fifth, **quality of CT plane may induce a significant measurement bias if it is not exactly axial. This was considered during our imaging study.**

Similarly, an excessive lumbar lordosis or scoliosis, or in contrast a reduction of lumbar lordosis may also introduce a measurement bias, altering the predictive performance of Δ PMI. This influencing factor was not integrated in our analysis. Sixth, several associated injuries might alter performance of Δ PMI by performing a local compression (retroperitoneal hematoma or spinal fracture), a distraction phenomenon (unstable lumbar spinal fracture) or a blockage of nerve afferents (spine cord injury). Our study did unfortunately not distinguish these mechanisms.

Seventh, calorie intake in our cohort was surprisingly low (median average daily global intake on the first week, 10.0 kcal/kg/day) despite an established nutrition protocol in our trauma ICU. Trauma patients are difficult to feed mainly due to sequenced surgical procedures, repeated CT imaging, but also severe abdominal trauma, reducing the use of enteral nutrition. However, high calorie intake is not a therapeutic goal in the first days of critical care. In contrast, calorie intake on day 7 was close to the recommendations in our cohort, which is comparable with other series. Moreover, oral calories were not considered in our data collection. **Eighth,** low physiological reserve and frailty status might influence the value of Δ PMI. These criteria could not be explored by our retrospective analysis. Finally, only psoas muscle area was studied in the present cohort, whereas psoas density analysis has also been proposed. A few studies have recently shown that muscle quality, more than muscle mass, could also be associated with negative outcomes [13,30,45].

Conclusion

In the present study, **acute post-traumatic muscle atrophy (APTMA)** was significantly associated with the duration of mechanical ventilation, ICU and hospital LOS, delayed infections

and thromboembolic events in severe trauma patients. Detection of **APTMA** by the decrease in psoas muscle area (Δ PMI) when a control abdominal CT scan is performed would identify most patients at risk of secondary complications.

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Fig. 1. Procedure for measuring psoas muscle area on a CT image.

Cross-sectional psoas muscle on a CT image was used at the third lumbar level. After confirmation of the correct horizontality of the axial plane (i.e., perpendicular to the longitudinal axis), right psoas muscle area was outlined manually to determine the psoas muscle index (PMI) expressed in mm²/m².

Fig. 2. Distribution of Δ PMI in the study population.

Decreasing rate of PMI between admission and second CT measure (Δ PMI) was calculated for each patient using the following equation and expressed as a percentage: Δ PMI = 100 × (admission PMI – second PMI)/admission PMI. Zero was attributed if the value was negative.

PMI, psoas muscle index; APTMA, acute post-traumatic muscle atrophy.

Fig. 3. Nutritional intake during the first 3 weeks of ICU stay.

Median average daily global intakes on the first week differed significantly between the low APTMA group (10 kcal/kg/day [IQR, 6–16 kcal/kg/day]), the moderate APTMA group (10 kcal/kg/day [IQR, 5–15 kcal/kg/day]) and the severe APTMA group (12 kcal/kg/day [IQR, 9–17 kcal/kg/day]); P=0.022) (Fig. 1).

ICU, intensive care unit; IQR, interquartile range; APTMA, acute post-traumatic muscle atrophy.

Fig. 4. Acute post-traumatic muscle atrophy, complications and outcome.

APTMA, acute post-traumatic muscle atrophy.

Table 1. Baseline characteristics according to severity of acute post-traumatic muscle atrophy.

	All patients (N=114)	Low APTMA group (n=29)	Moderate APTMA group (n=56)	Severe APTMA group (n=29)	P value
Anthropometric characteristics					
Age (years)	40 (25–54)	33 (23–51)	40 (25–54)	44 (28–65)	0.12 ^a
Men, n (%)	94 (82)	24 (83)	45 (80)	25 (86)	0.80 ^b
Weight (kg)	80 (68–89)	79 (66.5–95)	78.5 (67–84)	80 (72–91)	0.25 ^a
Height (cm)	177 (170–180)	177 (169–180)	175 (169–180)	178 (172–184)	0.31 ^a
BMI (kg/m ²)	22 (20–24)	22.2 (19.5–25.3)	21.5 (19.4–23.7)	22.2 (20.3–25.1)	0.32 ^a
<18, n (%)	11 (18)	4 (14)	5 (9)	2 (7)	0.30 ^b
18–20, n (%)	19 (17)	5 (17)	12 (21)	2 (7)	
20–25, n (%)	58 (51)	11 (38)	30 (54)	17 (59)	
25–30, n (%)	23 (20)	7 (24)	9 (16)	7 (24)	
>30, n (%)	3 (3)	2 (7)	0 (0)	1 (3)	
Mechanism of injury, n (%)					
Motor vehicle crash	67 (59)	17 (59)	31 (55)	19 (66)	0.64 ^b
Pedestrian	5 (4)	2 (7)	3 (5)	0 (0)	
Bicycle/motorcycle	17 (15)	5 (17)	7 (13)	5 (17)	
Fall	18 (16)	2 (7)	11 (20)	5 (17)	
Assault/crushing	7 (6)	3 (10)	4 (7)	0 (0)	
Severe injuries, n (%)					
Head AIS ≥3	39 (34)	9 (31)	17 (30)	13 (45)	0.38 ^b
Face AIS ≥3	9 (8)	3 (10)	5 (9)	1 (3)	0.67 ^b
Chest AIS ≥3	75 (66)	18 (62)	37 (66)	20 (69)	0.86 ^b
Abdominal AIS ≥3	69 (61)	19 (66)	33 (59)	17 (59)	0.82 ^b
Pelvic AIS ≥3	32 (28)	3 (10)	18 (32)	11 (38)	0.04 ^b
Extremity AIS ≥3	48 (42)	8 (28)	25 (45)	15 (52)	0.15 ^b
Severity criteria					
ISS	33 (25–41)	32 (25–38.5)	32.5 (22–41)	34 (29–43)	0.14 ^a
First 24 hours SAPS II	34 (24–45)	26 (19.5–38.5)	34 (24–45)	42 (34–50.5)	0.01 ^a
Massive transfusion, n (%)	30 (26)	4 (14)	14 (25)	12 (41)	0.055 ^b
Admission PTr	1.16 (1.08–1.30)	1.14 (1.11–1.18)	1.17 (1.04–1.36)	1.25 (1.13–1.41)	0.12 ^a
Admission haemoglobin (g/dL)	11.5 (9.5–13.2)	13 (9.8–13.4)	11.2 (9.6–13)	10.3 (9.2–11.9)	0.04 ^a

Data are expressed as median (interquartile range) or as the number of patients (percentage) as appropriate. AIS, Abbreviated Injury Scale; APTMA, acute post-traumatic muscle atrophy; BMI, body mass index; ISS, Injury Severity Score; SAPS II, Simplified Acute Physiology Score; PTr, prothrombin time ratio.

^aKruskal-Wallis test.

^b χ^2 test.

Table 2. CT scan measurements of psoas muscle.

	All patients (N=114)	Low APTMA group (n=29)	Moderate APTMA group (n=56)	Severe APTMA group (n=29)	<i>P</i> value ^a
Admission PMI (mm ² /m ²)	329 (257–403)	330 (249–453)	329 (273–382)	320 (244–432)	0.95
Second scan PMI (mm ² /m ²)	294 (234–362)	315 (243–431)	288 (242–332)	257 (158–332)	0.069
ΔPMI (mm ² /m ²)	39 (19–63)	14 (0–19)	39 (27–54)	81 (64–112)	<0.001
ΔPMI, ratio (%)	12 (6–19)	4 (0–6)	12 (9–15)	22 (20–28)	<0.001
Day of second CT scan	8 (6–10)	7 (5–11)	8 (6–12)	8 (6–10)	0.77

Data are expressed as median (interquartile range). **APTMA**, acute post-traumatic muscle atrophy; PMI, psoas muscle index, expressed as area (mm²/m²); ΔPMI, decreasing rate of PMI between admission and second CT measure.

^aKruskal-Wallis test.

^bχ² test.

Table 3. Outcomes according to degree of acute post-traumatic muscle atrophy.

	All patients (N=114)	Low APTMA group (n=29)	Moderate APTMA group (n=56)	Severe APTMA group (n=29)	P value ^a
Mechanical ventilation (days)	11 (5–20)	5 (2–10)	11 (5–18)	28 (15–36)	<0.001 ^a
Catecholamines use (days)	3 (1–8)	1 (0–3)	3 (1–7)	8 (3–13)	<0.001 ^a
RRT requirements, n (%)	13 (11)	1 (3)	5 (9)	7 (24)	0.056 ^b
Pneumonia, n (%)	43 (38)	7 (24)	18 (32)	18 (62)	0.006 ^b
Other sepsis, n (%)	33 (29)	3 (10)	17 (30)	13 (45)	0.014 ^b
Thromboembolic events, n (%)	37 (32.5)	5 (17)	18 (32)	14 (48)	0.041 ^b
ICU LOS (days)	18 (12–318)	13 (9–17)	18 (12–24)	38 (24–50)	<0.001 ^a
Hospital LOS (days)	29 (19–45)	19 (15–29)	29 (20–39)	48 (31–61)	<0.001 ^a
Mortality, n (%)	11 (10%)	1 (3)	5 (9)	5 (17)	0.20 ^b

Data are expressed as median (interquartile range) or as number of patients or events (percentage) as appropriate. APTMA, acute post-traumatic muscle atrophy; ICU, intensive care unit; LOS, length of stay; RRT, renal replacement therapy.

^aKruskal-Wallis test.

^b χ^2 test.

Table 4. Multivariable linear regression adjustment for Δ PMI.

Outcomes variables	Adjusted β Δ PMI	95% confidence interval	<i>t</i>	<i>P</i>
Model 1: mechanical ventilation duration	0.78	0.61–0.95	9.21	<0.001
Model 2: catecholamine duration	0.23	0.13–0.33	4.71	<0.001
Model 3: ICU LOS	0.91	0.66–1.15	7.22	<0.001
Model 4: hospital LOS	0.63	0.31–0.96	3.85	<0.001

The following variables were initially included in the multivariable analysis in addition to Δ PMI: age, BMI, sex, ISS, severe anatomic injuries based on AIS score, admission white blood cell count, massive transfusion needs, invasive surgical interventions, and cumulative 7 days nutritional intake. Final regression models only conserved significant variables.

β , unstandardized regression coefficient; BMI, body mass index; ICU, intensive care unit; ISS, Injury Severity Score; LOS, length of stay; PMI, psoas muscle index.

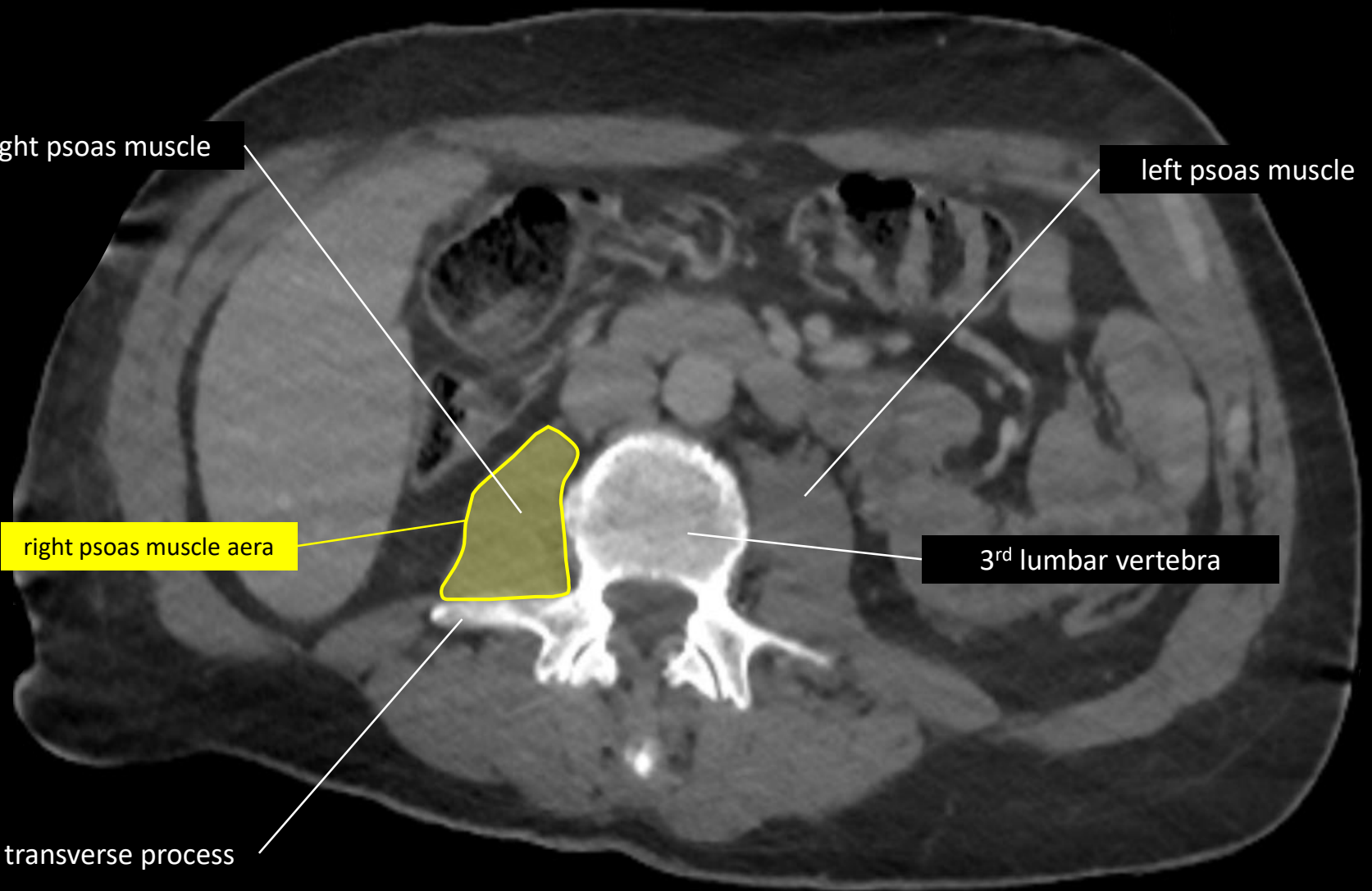
right psoas muscle

left psoas muscle

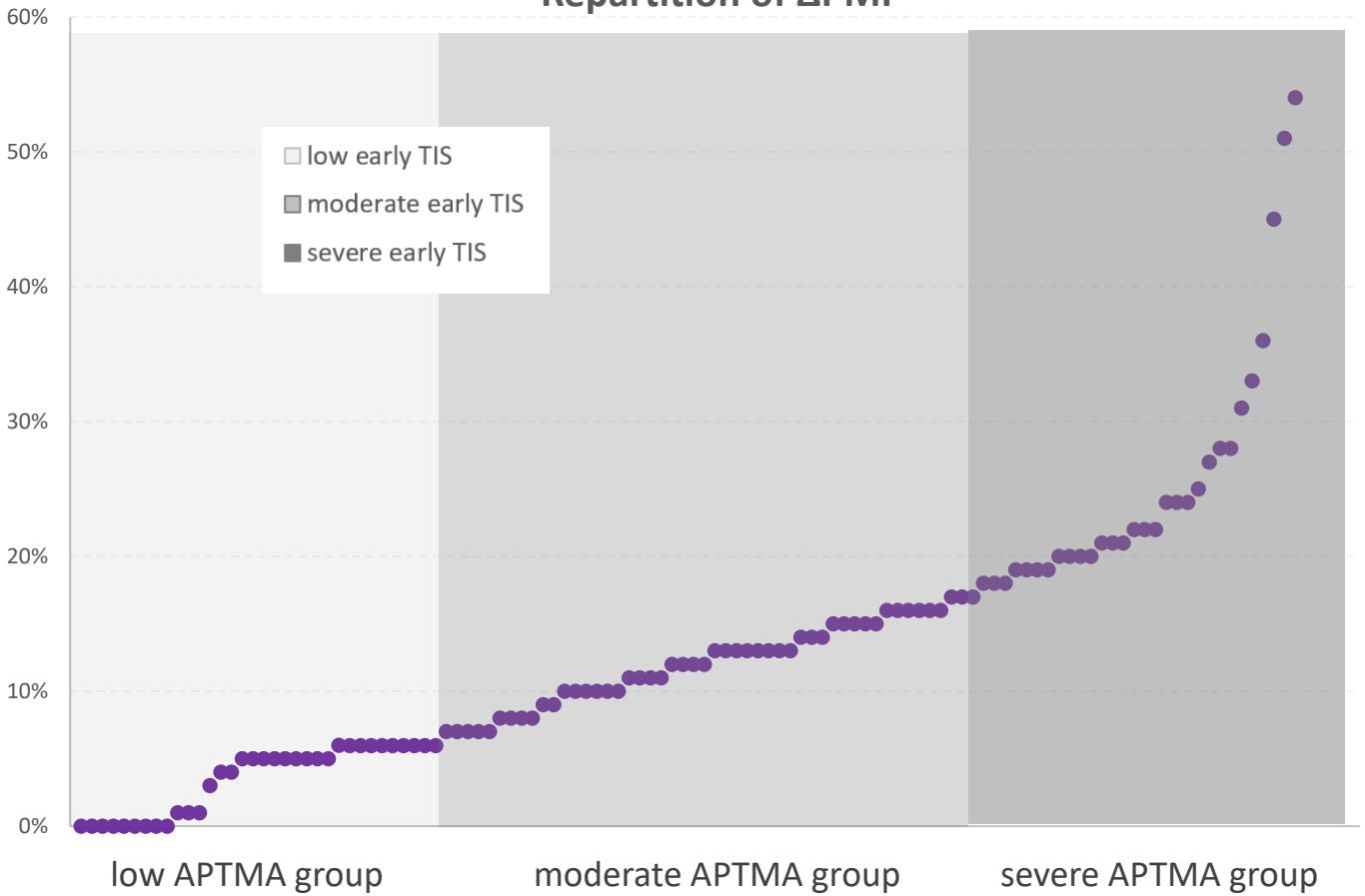
right psoas muscle area

3rd lumbar vertebra

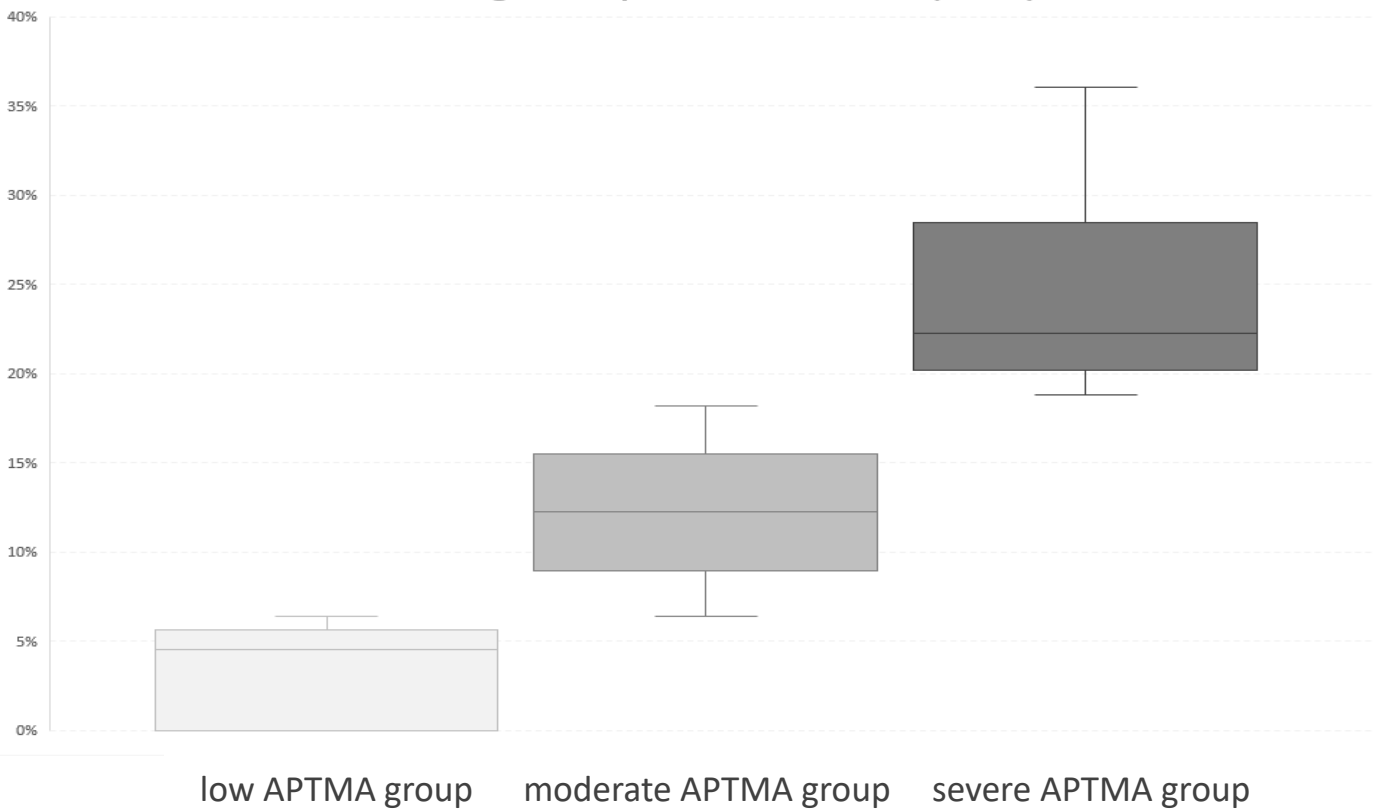
transverse process



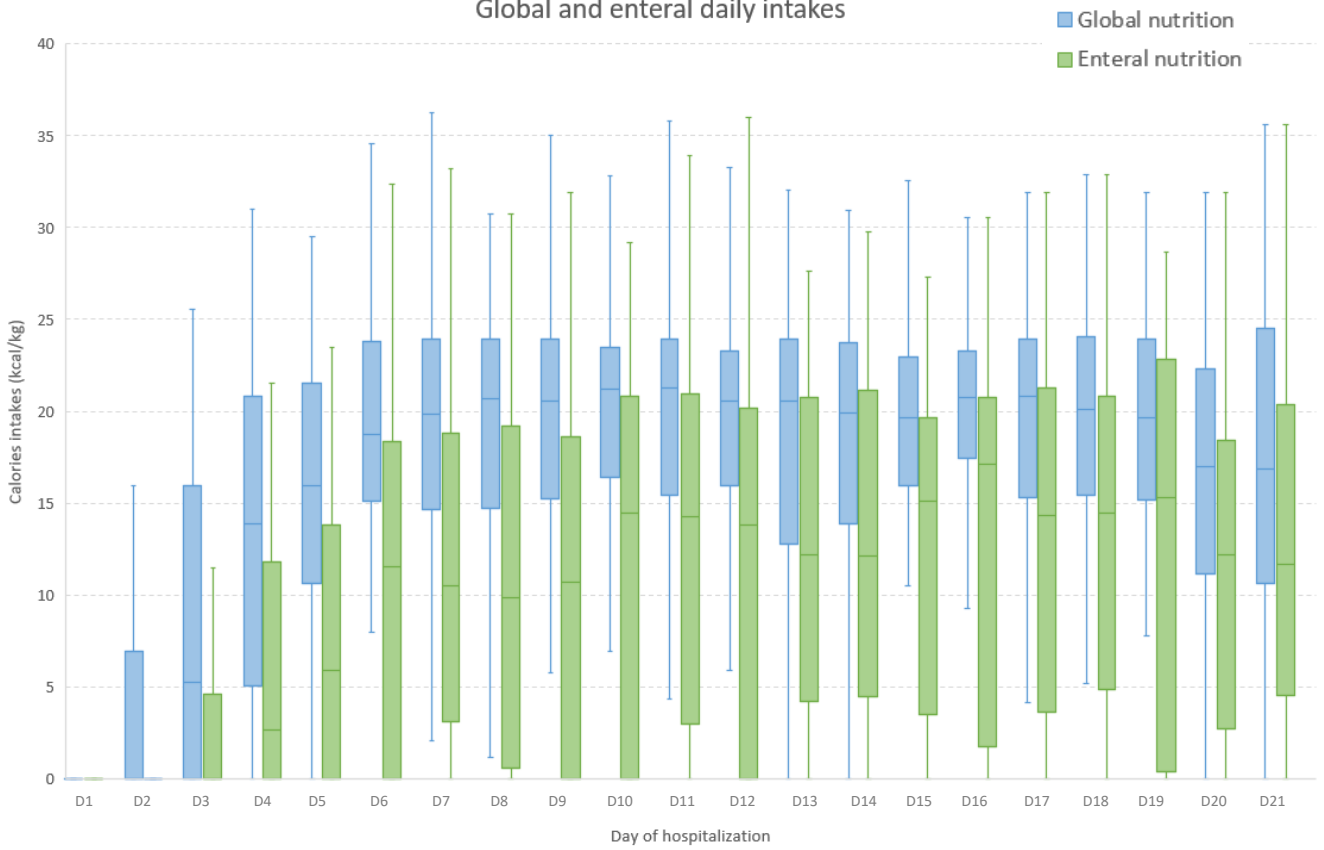
Repartition of Δ PMI



Decreasing rate of psoas muscle index (Δ PMI)



Global and enteral daily intakes



Global nutritional intakes

