Current Research in Translational Medicine 67 (2019) 93–99

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Original article

Sarcopenic obesity derived from PET/CT predicts mortality in lymphoma patients undergoing hematopoietic stem cell transplantation

J. Jabbour[a,b], B. Manana[c], A. Zahreddine[d], C. Saade[e], M. Charafeddine[c], A. Bazarbachi[d], D. Blaise[f,g], J. El-Cheikh[d,*]

[a] Department of Clinical Nutrition, American University of Beirut Medical Center, Beirut, Lebanon
[b] Doctoral School of Life Sciences and Health, Aix Marseille Université, Marseille, France
[c] Division of Hematology/Oncology, Department of Internal Medicine, American University of Beirut Medical Center, Beirut, Lebanon
[d] Bone Marrow Transplantation Program, Department of Internal Medicine, American University of Beirut Medical Center, Beirut, Lebanon
[e] Department of Radiology, American University of Beirut Medical Center, Beirut, Lebanon
[f] Hematology Department, Transplantation Unit, Paoli Calmettes Institute, Marseille, France
[g] Centre de Recherche sur le Cancer de Marseille (CRCM), Inserm U 1068, Marseille, France

ARTICLE INFO

Article history:
Received 5 September 2018
Accepted 15 December 2018
Available online 21 December 2018

Keywords:
Sarcopenic obesity
PET/CT
Hematopoietic stem cell transplantation
Lymphoma

ABSTRACT

Background: Sarcopenic Obesity (SO) is associated with worse survival among chemotherapy recipients. Research on SO is scarce among lymphoma patients receiving Hematopoietic Stem Cell Transplantation (HSCT).
Aim: assess prevalence of SO pre-HSCT (T0) and 3 months post-HSCT (T1) in lymphoma patients and determine the power of SO at T0 and T1 in predicting survival.
Methods: Consecutive patients (age ≥16 years) having B and T cell lymphoma who underwent SCT and who had PET/CT scan pre-SCT and 3 months post SCT were included in the study. A cross sectional image was analyzed at the level of the 3rd Lumber Vertebrae to assess body composition parameters.
Results: 93 patients [mean age: 38 (range: 17–70 years), 52 (55.9%) males, 45 (48%) Hodgkin and 48 (52%) Non-Hodgkin lymphoma, 81 (87%) autologous and 12 (13%) allogeneic SCT)] met the inclusion criteria. From T0 to T1, Sarcopenia rates increased (27% at T0 to 38% at T1, $p = 0.013$), Visceral adiposity decreased (46% at T0 to 30% at T1, $p = 0.03$) and SO decreased (42% at T0 to 20% at T1, $p < 0.01$). Length of stay, overall survival and progression free survival were significantly better in patients without sarcopenic obesity at T1. Cox-regression revealed SO at T1 was a risk factor for mortality [Adjusted Hazards Ratio = 8.2 (95% Confidence Interval: 1.9–36.2)].
Conclusion: Sarcopenic obesity, prevalent in 42% of patients pre-HSCT, decreased 3 months post HSCT as lymphoma patients lost skeletal muscle and visceral adipose tissues. SO at T1 was the most impactful risk factor for mortality.

Introduction

Hematopoietic Stem Cell Transplantation (HSCT) is used in the treatment of hematologic malignances, as well as autoimmune and metabolic disorders [1]. HSCT is associated with gastro-intestinal damage, decreased protein synthesis and intake and complications that increase the risk of sarcopenia and metabolic syndrome [2–5]. Body weight and Body Mass Index (BMI), the conventionally collected anthropometric measures, poorly characterize body composition changes, as there exists a wide variation in adipose tissues and lean body masses within each BMI category [6–8]. Computed Tomography (CT) scans at the level of the 3rd Lumbar Vertebrae (L3) are considered the golden standard to identify sarcopenia and discern adipose tissue types (subcutaneous, visceral, and intermuscular) in cancer patients [9–11]. Among HSCT recipients, Lymphoma patients' body composition status can be studied thoroughly as PET/CT evaluation is performed regularly for cancer staging. A recent study assessing sarcopenia in lymphoma patients revealed prevalence rates of 49%, 51% and 52% pre HSCT, 1 year and 2.5 years post HSCT, respectively [2].

* Corresponding author at: Department of Internal Medicine, American University of Beirut Medical Center, PO BOX 11-0236, Riad El-Solh, 1107-2020, Beirut, Lebanon.
E-mail address: je46@aub.edu.lb (J. El-Cheikh).

http://dx.doi.org/10.1016/j.retram.2018.12.001
2452-3186/

Sarcopenia was also shown to be associated with longer length stay, more HSCT complications, worse disease free survival yet paradoxically one study showed a lower risk of Graft versus Host Disease (GvHD) [2,12,13].

Sarcopenic obesity (SO) is a condition where sarcopenia co-exists with visceral obesity. Visceral Adipose Tissues (VAT) are considered the culprit adipose tissues with pro inflammatory and tumorigenic properties. VAT were shown to be negative prognostic indices of Progression Free Survival (PFS) and Overall Survival (OS) in patients with diffuse large B cell lymphoma [2,14]. In Lymphoma patients, SO is associated with chemotherapy toxicity, poor functional status, worse survival and delayed identification as subjects are mistakenly thought to be protected from sarcopenia [14–16]. To date, research is still not very clear on the acute changes in the Body Composition Parameters (BCP) acutely post HSCT and the power of these parameters in predicting major outcomes in lymphoma patients. The primary aim of this study was to assess prevalence and changes in SO from pre transplantation (T0) to 3 months post HSCT (T1). A secondary outcome was to evaluate the power of SO in predicting mortality in lymphoma patients.

Material and methods

This study is a retrospective cohort study that follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for the conduct and reporting of observational cohort studies [17].

Lymphoma patients planned for SCT undergo CT for their abdomen before transplantation and in the first 3 months post SCT as part of their medical work-up. Consecutive patients aged 16 years and older having B and T lymphoma that underwent SCT at the American University of Beirut Medical Center (AUBMC) between January 2006 and June 2016 were identified by the research team. Patients with missing pre or post SCT PET/ CT scans or missing height were excluded from the study. Similarly, patients whose medical charts were not available for review were also excluded from the study. AUBMC Picture Archiving and Communications System and Philips IntelliSpace Portal; Version Number: 7.0.0.24504® were used to review PET/CT scans of the identified patients. A single research assistant was trained and supervised by a senior radiologist to perform the measures. A cross sectional image was chosen at the level of the L3 near the midpoint, in the region extending from L3 to the iliac crest. To quantify skeletal muscle and adipose tissue areas, lines were drawn around the regions of interest (Abdominal perimeter, outer and inner perimeters of the abdominal muscles and visceral fat) [18]. Calculated Body Composition Parameters (BCP) were TAT (cm^2), VAT (cm^2), SMI (cm^2/m^2) and WC (cm).

Data on disease status, disease progression, conditioning regimen and intensity, engraftment time, nutritional indicators (BMI at admission and discharge, weight loss, nutrition support during admission), re-hospitalization, length of stay and mortality were collected retrospectively from the electronic health records. The hematopoietic cell transplantation-comorbidity index (HCT-CI) score was used for risk assessment pre transplantation [19].

Definitions

When presented as a categorical variable, BMI categorization followed the World Health Organization's definition: underweight (<18.5 kg/m^2), normal (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2) and obese (≥30 kg/m^2). SMI (cm^2/m^2) was defined as the skeletal muscle area normalized to height (measured in m^2).. Sarcopenia was defined using SMI cut off values of <52.4 cm^2/m^2 for males and <38.9 cm^2/m^2 for females [20]. Visceral Obesity (VO) was present when VAT > 163.8 cm^2 in males and >80.1 cm^2 for females as defined by Doyle's research on obesity in cancer [21]. SO was defined as having an elevated VAT/SMI ratio (>2.8 in males and >2.4 in females) as suggested by Sandini [22].

Transplant related outcomes

Conditioning intensity was categorized as Myeloablative conditioning and Reduced Intensity Conditioning [23]. Relapse related mortality was defined as death that occurred due to disease progression. Transplant related mortality was defined as death that occurred as a consequence of transplantation. PFS was defined as the time between transplantation and relapse or the date of the last clinical follow up, whichever occurred first. OS was defined as the time between transplantation and death or the date of the last clinical follow up, whichever occurred first. Disease status was defined as one of 3 categories: Complete remission, partial remission/stable disease and progressive disease/relapse. Disease status was assessed prior to transplantation, in the first 3 months post transplantation and once yearly thereafter.

Ethical considerations

The Institutional Review Board of the American University of Beirut reviewed and approved the study protocol. The research team followed guidelines for biomedical ethics and the recommendations of the Declaration of Helsinki when designing and conducting the study. The study was registered in the ClinicalTrial.gov database (identifier: NCT02983643).

Statistical analysis

Assuming a confidence interval of 95%, a margin of error of 5%, the sample size needed was 72 patients to measure an expected difference of 25% in SMI between pre SCT and 3 months post SCT. The rationale for the sample size calculation was based on a study of BCP changes among SCT patients [3]. In this study, the research team opted to review charts of target population in AUBMC from 2006 until 2016. Patients with missing PET/ CT scans and height were excluded from the study due to inability to calculate SMI and other BCP. Patients' characteristics were presented as counts and percentages and assessed using Chi-square or Fisher Exact tests for low counts for categorical variables. Continuous variables were presented as means ± standard deviations (SD) and assessed using independent t-tests or Mann Whitney tests. Changes in continuous variables before and post transplantation were assessed through paired *t*-test or Wilcoxon Rank Sum tests. Shapiro-Wilk test was used to assess normality and decide on the statistical tests. Data analysis was stratified by gender since BCP are known to be different across gender categories and cut-off points are gender based.

Paired analysis of sarcopenia, visceral obesity and SO between T0 and T1 was performed through Mcnemar's test. OS was analyzed after adjusting for the clinically relevant risk factors, via univariate and multivariate Cox regression. Models were computed using the backward conditional method (retention of variables with p values ≤0.25) using clinically relevant predictors: gender, underlying disease, age, type of transplantation, status at transplantation, conditioning intensity, HCT-CI and VAT/SMI pre SCT as a body composition predictor [24]. Probability of OS and PFS were calculated with Kaplan Meier. Comparisons between groups were performed using log-rank statistics. Multivariate logistic regression was performed for SO at T0 and T1 using the backward conditional method (retention of variables with p values≤0.25). Statistical significance tests were two-sided and significance was reached when p value<0.05. Analysis was performed using SPSS® version 24 (IBM, Armonk, New York, USA).

Results

A total of 93 patients with lymphoma, having undergone HSCT in AUBMC between 2006 and 2016 and meeting the inclusion criteria were enrolled in the study (Supplementary Fig. 1). All patients underwent imaging at T0 (mean of 20 days pre SCT) and T1 (mean of 78 days post SCT) and 91% of the patients were receiving their first transplant. The mean age of the sample was 38 years (range: 17–70 years) and 55.9% of the sample were males. Data is presented by gender since BCP differ significantly across gender (Table 1). Autologous HSCT was more prevalent in both genders (87% and 88% of males and females, respectively). The rest underwent allogeneic HSCT. Median time from diagnosis until transplantation was 24 months in both groups. The majority of participants (88% of males vs. 93% of females) were alive at the last follow up (median follow up: 13 months) and mean OS was higher in females compared to males (89 vs. 85 months). Factors that differed statistically between genders were disease progression (39% vs. 17%), mean weight (88 vs. 65 Kg), BMI (29 Kg/m^2 vs. 25 Kg/m^2), and weight loss during hospital stay (4.6% vs. 2.5%) with all of them being higher/larger among males (Table 1). Variables were also presented by death status, comparing patients who survived to those who passed away (Supplementary Table 1). As for outcomes post HSCT, variables were similar across groups except for progression that was higher in males (39% vs. 17%, p = 0.024). Most of the patients (86%) were in complete remission and 42% of the allogeneic HSCT patients had GvHD at last follow up (Supplementary Table 2).

Body composition parameters

Adipose tissue and skeletal muscle areas were all larger in males and tended to decrease post transplantation in both genders (Supplementary Tables 2 and 3; Fig. 1). Statistically significant changes post transplantation were for TAT, VAT, SMI, VAT/SMI and WC in males and VAT, VAT/SMI and WC in females (Supplementary Table 3). The highest observed reduction was for TAT (reductions in 35 cm^2 in males and 16 cm^2 in females). Mean SMI decreased more pronouncedly in males compared to females [reduction in 2.9 cm^2/m^2 ($p < 0.01$) vs. 1.1 cm^2/m^2 ($p = 0.16$)]. In parallel, sarcopenia rates increased significantly in males from pre to post transplantation (25% vs. 42%, p = 0.01) compared to females (29% vs. 32%, p = 1) (Supplementary Table 4). Cut off points for the highest tertile for VAT/SMI was found to be 2.99 pre SCT and 2.28 post SCT. Group analysis (data not shown) revealed patients receiving allogeneic HSCT had a sharper decrease in SMI (57cm^2/m^2 at T0 vs. 48cm^2/m^2, p = 0.006 in allogeneic vs. 52 cm^2/m^2 at T0 vs. 50cm^2/m^2, p = 0.015) and visceral obesity (58% at T0 vs. 50% at T1 in allogeneic vs. 31% at T0 vs. 27% at T1 in autologous) and increase in sarcopenia (17% at T0 vs. 50% at T1, p = 0.13 in allogeneic vs. 28% at T0 vs. 36% at T1, p = 0.11 in autologous).

Studying the changes in the overall sample from T0 until T1, we noted that sarcopenia rates increased (27% at T0 to 38% at T1, p = 0.013), visceral obesity decreased (46% at T0 to 30% at T1, p = 0.03) and SO decreased (46% at T0 to 30% at T1, $p < 0.01$). Patients with SO had a longer mean length of hospital stay (22.5 vs. 25.3 days, p = 0.047), and a lower survival compared to those with no SO. Fig. 2 demonstrates the Kaplan Meier survival curve of OS and PFS predicted by SO at T1. Patients without SO had a mean OS of 93 months (95% Confidence Interval (CI): 83–103 months) and a mean PFS of 68 months (95% CI: 54–83) compared to those with SO who had a mean OS of 65 months (95% CI: 45–86 months) and mean PFS of 35 months (95%CI: 20–49).

Univariate and multivariate analysis

Univariate and multivariate Cox regression for OS are presented in Table 2. Age at transplantation, underlying disease and SO at T1 were the variables entered in the multivariate cox regression as they had p values< 0.25 in univariate analysis. In the multivariate analysis, these three variables were statistically significant. Age was not associated with increased mortality risk [Adjusted Hazards Ratio (AHR): 0.92, 95% CI: 0.87-0.99, p value = 0.017], whereas having non-Hodgkin lymphoma (NHL) (AHR: 6.45, 95% CI: 1.26–33.1, p value = 0.026), and SO (AHR: 4.8, 95% CI: 1.14–20.5, p value = 0.032) increased hazards of mortality.

Table 1
Patients Characteristics pre-transplantation presented by Gender.

Variable		Males (n = 52)	Females (n = 41)	P value
Age (years) at HSCT, mean ± SD		38.6 ± 14	36.6 ± 13	0.42
Disease, n (%)	**Hodgkin**	24 (46)	21 (51)	0.63
	Non-Hodgkin	28 (54)	20 (49)	
Type of HSCT, n (%)	**Autologous**	45 (87)	36 (88)	0.86
	Allogeneic	7 (14)	5 (12)	
Disease Status at HSCT, n (%)	**CR**	27 (52)	18 (44)	0.49
	PR/SD	19 (37)	20 (49)	0.57
	PD / Relapse	6 (11.5)	3 (7.3)	
Time from diagnosis to HSCT (months), median (range)		24 (4-284)	24 (2-141)	0.88
Previous chemotherapy lines of treatment, mean ± SD		2 ± 1.1	2.2 ± 1.4	0.64
HCT-CI score, n (%)	**0**	30 (58)	28 (68)	0.57
	1	16 (31)	9 (22)	
	≥2	6 (11)	4 (10)	
Conditioning Intensity, n (%)	**Myeolablative Conditioning**	50 (96)	39 (95)	0.81
	RIC	2 (4)	2 (5)	
ATG administration, n (%)		2 (4)	2 (5)	0.81
Weight (Kg) at admission, mean ± SD		88.1 ± 19	65.2 ± 14	<0.01
BMI (Kg/m^2), mean ± SD		28.6 ± 5.2	25 ± 4.9	<0.01
Serum albumin at admission (gm/dL), mean ± SD		42.8 ± 5.2	44 ± 3.2	0.55
Weight Loss (%) during hospital stay, mean ± SD		4.6 ± 4.2	2.5 ± 2.9	0.025
Prednisone equivalent* (mg), mean ± SD		218 ± 668	119 ± 94	0.53
Time to platelet engraftment (days), mean ± SD		9.1 ± 2.8	10.8 ± 6.5	0.38
Time to WBC engraftment (days), mean ± SD		10 ± 2.0	10.5 ± 2.5	0.35
Length of stay (days), mean ± SD		23 ± 5.3	26 ± 8.3	0.092

SD: standard deviation, HSCT: Hematopoietic Stem Cell Transplantation, CR: Complete Remission, PR: Partial Remission, SD: Stable Disease, PD: Progressive Disease, RIC/Reduced Intensity Conditioning, ATG: Anti-thymocyte globulin administration, HCT-CI: Hematopoietic Cell Transplantation-Comorbidity Index, BMI: Body Mass Index.

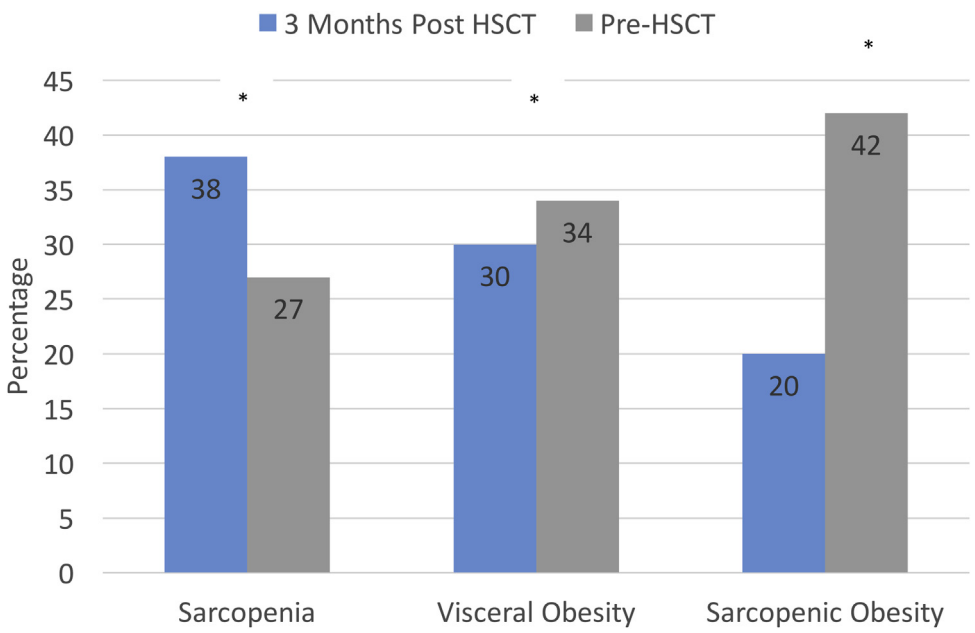

Fig. 1. Bar Graph reflecting prevalence of sarcopenia, visceral adiposity and sarcopenic obesity pre HSCT and 3 months post HSCT.
*p value<0.05 for paired assessment

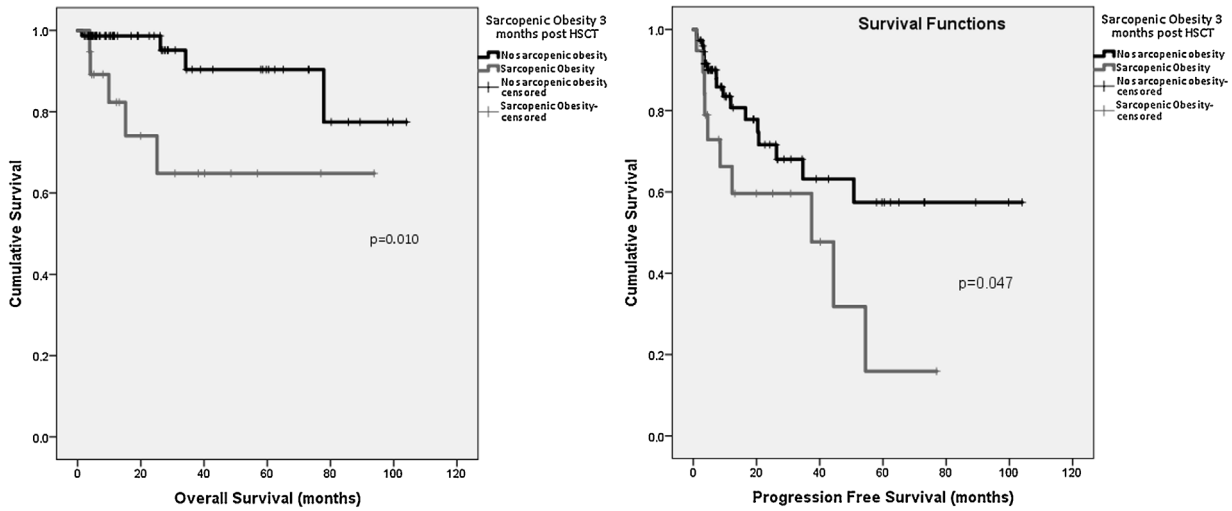

Fig. 2. Kaplan Meier of overall and progression free survival presented by sarcopenic obesity categories assessed 3 months post transplantation.

Multivariate regression showed that patients who are older and those who have a higher admission BMI had a higher risk of SO pre-HSCT (Table 3). Moreover, age, gender and Total Parenteral Nutrition (TPN) use were predictors of SO post HSCT. Males and older patients and those who needed TPN had an increased risk of having elevated VAT/SMI when compared to females, young, and those who were on enteral or oral feeding, respectively (Table 3).

Discussion

This cohort study presented baseline data on the changes in BCP pre and 3 months post transplantation among lymphoma patients. SO was highly prevalent pre HSCT and decreased 3 months post HSCT as VAT and SMI tended to decrease. SO 3 months post HSCT was associated with longer hospitalization and shorter OS and PFS. SO at T1 predicted mortality in addition to commonly known risk factors such as age and underlying disease.

SO, originally reserved for the aging population, is becoming more prevalent among younger adults with cancer. As seen in our study, SO was highly prevalent before even starting HSCT in a sample of young adults (mean age = 38 years). Even though Sarcopenia rates increased by 11% in the first 3 months post HSCT, SO deceased to 20% in parallel with the VAT reduction in the overall sample. These findings complement previous findings reflecting acute worsening of malnutrition in the first 3 months post HSCT [25,26].

Among HSCT patients, sarcopenia was shown to be associated with chronic GvHD, a low performance status, an increased steroid administration and lower survival [3,13]. There was a correlation between low Fat Free Mass Index (FFMI) and high FMI and length of stay [3]. Our study confirmed the negative outcomes associated with SO on mortality and length of hospital stay, yet, it discerned increased visceral fat as a main culprit among adipose tissues. As for the nutritionally relevant predictors of SO, use of parenteral

Table 2
Cox Hazards Analysis of Mortality.

Variable	Univariate Analysis			Multivariate Analysis		
	HR	95% CI	P value	AHR	95% CI	P value
Age	0.96	0.91-1.0	0.24	0.93	0.87-0.99	0.015
Female	0.68	0.17-2.7	0.58			
Allogeneic Transplantation	0.45	0.09-2.2	0.33			
Non-Hodgkin Lymphoma	3.3	0.69-16.2	0.14	4. 5	0.9-22.4	0.067
Conditioning Intensity			0.63			
Reduced Intensity Conditioning	Not applicable[a]					
Status at Transplant			0.55			
Complete Remission	1 (referent)					
Residual Disease	0.46	0.11-1.9	0.46			
Progressive Disease	0	0	0.99			
Body Mass Index			0.33			
Underweight	6.4	0.63-64.4	0.12			
Normal BMI	1 (referent)					
Overweight	0.5	0.053-5.3	0.52			
Obese	1.1	0.23-5.6	0.89			
Sarcopenic Obesity 3 months post HSCT	4.9	1.3-18.3	0.019	8.2	1.9-36.2	0.006

Variables that had a p value ≤0.25 in the univariate regression are presented in the multivariate analysis. AHR = Adjusted Hazards Ratio, 95%CI: 95% confidence interval.
[a] None of the participants from the Reduced Intensity Conditioning group passed away; adjusted odds ratio could not be calculated for this category.

Table 3
Multivariate Regression Models showing factors associated with high Sarcopenic Obesity pre and 3 months post transplantation.

Sarcopenic Obesity	Variable	Adjusted Odds Ratio	P value
Pre HSCT	**Age at transplant (years)**	1.08 (1.03-1.13)	<0.01
	BMI pre HSCT		0.017
	Healthy BMI	1 (referent)	
	Underweight BMI	0	1
	Overweight BMI	6.45 (1.3-32.1)	0.023
	Obese BMI	14.8 (2.82-77.1)	<0.01
3 months Post HSCT	**Age at transplant (years)**	1.04 (0.99-12.1)	0.059
	Females	0.24 (0.058-0.99)	0.048
	TPN	3.4 (0.95-12.1)	0.060

HSCT: Stem Cell Transplantation, VAT: Visceral Adipose Tissues, SMI: Skeletal Muscle Index. BMI: Body Mass Index.
Variables entered in the model of sarcopenic obesity pre HSCT: Type of transplantation, age at transplant (years), gender, disease, status at transplant, conditioning intensity, hematopoietic cell transplant-co-morbidity index, albumin at admission, BMI at admission.
Variables entered in the model of sarcopenic obesity 3 months post HSCT: Type of transplantation, age at transplant (years), gender, disease, status at transplant, conditioning intensity, hematopoietic cell transplant-co-morbidity index, incidence of graft versus host disease, percent weight loss during hospital stay, total steroid during hospital stay, BMI at discharge, use of TPN during HSCT hospital stay.

nutrition and obesity stand out as risk factors. Except for few studies, majority of literature so far suggests a higher risk of mortality among obese patients undergoing HSCT [27–32]. Obesity was previously associated with lower rates of sarcopenia [12]. In our study, being overweight was associated with lower odds of sarcopenia and higher odds of SO. Moreover, SO was superior to BMI in predicting survival in multivariate regression and 80% of the sarcopenic patients had a normal BMI, confirming the poor characterization of malnutrition by BMI. As for the use of nutrition support, previous studies among HSCT patients put forward the benefits of enteral nutrition over parenteral nutrition on GvHD incidence, neutrophil engraftment and OS [33–35]. In our study, use of parenteral nutrition was a risk factor for SO compared to oral feeding in patients who were unable to feed well because of treatment side effects.

Allogeneic patients had a sharper increase in sarcopenia compared to autologous HSCT. This confirms previous findings showing that sarcopenia rates reached 78% at 2.5 years post allogeneic HSCT compared to autologous HSCT where sarcopenia was present in 42% of the patients [12]. This discrepancy between HSCT types can be explained by the complications of allogeneic HSCT such as veno occlusive disease, GvHD and opportunistic infections that put patients in a catabolic state and expose them to extensive steroid use, which is known to be associated with muscle wasting and the metabolic syndrome [5,36,37].

Centers should consider making use of the readily available CTs to predict OS, shorten hospitalization and potentially to reduce toxicity by adjusting chemotherapy dosage based on lean mass rather than on body surface area [38]. CTs are considered gold methods for body composition assessment. When CT are not performed for disease evaluation, alternative methods of body composition should be sought [39]. Waist circumference is not a suitable candidate as it does not differentiate between subcutaneous and visceral adipose tissues. Bio Impedance Analysis (BIA) is a non-invasive and affordable technique that provides assessment of BCP [40–42]. Even though BIA measurements are considered inferior to CT as their results are affected by many confounders (hydration status, use of alcohol, exercise, menstruation for females, etc.), but they do not involve exposure to radiation, are affordable and require a short technician training time. BIA techniques currently used underestimate VAT in healthy individuals but have an acceptable correlation compared to CT with the best correlation for dual BIA ($r = 0.89$ for dual BIA, $p < 0.05$ vs. $r = 0.64, p < 0.05$ for whole body BIA) [41]. SMI evaluated via BIA has an acceptable correlation and a significant kappa agreement when compared to SMI assessed via CT in colorectal cancer patients [43]. Future studies should compare agreement of BIA and PET/CT in HHSCT to draw conclusions for BIA use in daily practice.

When exploring risk factors of SO, exercise and diet interventions are worth mentioning. Physical activity interventions

among HSCT patients during hospital stay and post discharge were effective in improving quality of life, reducing fatigue and improving survival [44,45]. SMI changes were not assessed in these studies. Yet a plausible explanation to the improvement in survival might be the increase in SMI and the reduction in visceral fat. As for the dietary interventions, higher intake of polyunsaturated fatty acids compared to saturated fatty acids was associated with a higher FFMI. Saturated fatty acids and trans fatty acids have been associated with an increase in fat free mass loss and high intake of fructose syrup was associated with an increase in visceral adiposity [46]. Future interventions can assess the effect of physical activity interventions and diet modulation on reducing the SO and consequently the risk of death among HSCT patients.

This study had several limitations. Due to the retrospective nature of the study, some variables such as patients' caloric and protein intake, handgrip strength, fluid balance, oral mucositis, and GI toxicity were not available. These variables would have allowed for a complete nutritional assessment of malnutrition. Moreover, the small number of patients in the allogeneic HSCT group might have affected the power of the group analysis results. Finally, a longer follow up would have provided a more comprehensive picture on the evolution of BCP post transplantation and the impact on chronic GvHD and long term survival.

Conclusion

This study presents novel data on prevalence rates of sarcopenic obesity among lymphoma patients in the acute peri transplantation phase as assessed by PET/CT imaging. SO was prevalent in 42% of the sample pre HSCT. Even though sarcopenia increased significantly 3 months post HSCT, sarcopenic obesity decreased to 20% reflecting the diminution in visceral adipose tissues. Patients with sarcopenic obesity were more likely to have extended hospitalization and reduced overall and progression free survival compared to their healthy peers. Future directions should aim to validate these findings in prospective cohorts stratified by HSCT type and should focus on measuring sarcopenic obesity when assessing the effectiveness of medical, physical activity and nutrition interventions among HSCT patients.

Conflict of interest

The authors have no conflicts of interest to declare.

Funding

No funding was received for this study.

Acknowledgements

The author Jana Jabbour would like to acknowledge the training received under the Scholars in HeAlth Research Program (SHARP) that supported her translational research skills.

The research team would like to thank the nursing staff for providing excellent care for our patients and the physicians in the Hematology and Oncology division at the American University of Beirut Medical Center and referring physicians from Lebanon and the Middle East region for their significant contributions and dedicated patients' care.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.retram.2018.12.001.

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