ORIGINAL ARTICLE

Nr 2023;13 (3):484-493

Peripheral Muscle Function and Myoelectric Activity of the Suprahyoid Region in Deglutition of Post-COVID-19 Patients

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DOI:
10.32098/mltj.03.2023.19

LEVEL OF EVIDENCE: 4

SUMMARY

Objective. To investigate the prevalence of sarcopenia and its association with myoelectric activity of the SH region in post-COVID-19 patients, stratified by disease severity and gender**.**

Methods. A cross-sectional study conducted in the post-COVID-19 Outpatient Clinic of a University Hospital. The following outcomes were assessed: swallowing (Dysphagia Risk Evaluation Protocol), electromyography of the SH region, muscle strength and muscle mass (dynamometry, ultrasound, and bioimpedance analysis).

Results. The sample consisted of 50 patients (50.4 ± 13.35 years), who were admitted to the COVID-19 ICU and referred to the Outpatient Clinic. Critical-COVID group (n = 19) had a loss of muscle strength, without loss of muscle mass, no altered myoelectric activity of the SH region. Deglutition was classified as normal. Female patients showed low strength and male patients presented loss of muscle mass, in both groups. In the Severe-COVID group (n = 31), female patients had higher myoelectric activity in the SH region at rest, when deglutition pasty and when swallowing liquids, and at the clinical evaluation of swallowing, multiple deglutition in the pasty consistency and coughing in the liquid consistency. The correlations were significant only in the Severe-COVID group.

Conclusions. Male Critical-COVID patients showed sarcopenia, while female patients demonstrated pre-sarcopenia. The correlation observed in the Severe-COVID group, suggests that COVID-19 may compromise the muscles involved in swallowing even in non-critical patients. It is noteworthy the evaluation of these outcomes in post-COVID-19 patients to focus on individualized rehabilitation plan to provide functional recovery after hospital discharge.

KEY WORDS

COVID-19; deglutition; intensive care units; muscles; sarcopenia.

INTRODUCTION

Severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) is a novel, highly infectious respiratory pathogen responsible for Coronavirus disease 2019 (COVID-19) (1).

Although COVID-19 is a respiratory disease, it has a multi-systemic character, which in 20% of the cases can evolve to a severe form, with the need for admission to the Intensive Care Unit (ICU) (2). In this sense, some factors are determinants for the development of severe symptoms such as male gender, advanced age, obesity, smoking history, hypertension, and diabetes (3).

Studies demonstrated that critically ill patients, infected with COVID-19, often exhibit musculoskeletal impairment (4). Such changes have been attributed to the direct and indirect effects of the exacerbated inflammatory process, characteristic of the disease. Besides the process of muscle catabolism triggered by long periods in ICU, prolonged immobilization, nutritional imbalance, and administration of medications (5). Thus, this critical phase, marked by intense protein destruction and hypercatabolism and prolonged physical inactivity, leads to loss of muscle strength, mass, and function (4), which characterizes sarcopenia (6).

Peripheral muscle weakness is an independent predictor of mortality to increased mechanical ventilation time, and ICU stays (7). In a study of 196 COVID-19 patients, greater peripheral muscle strength was associated with shorter hospital stays (8). Also, in a recent study, critically ill patients hospitalized for COVID-19 showed a reduction in peripheral muscle strength, assessed by dynamometry, when compared to non-severe patients (9). Regarding muscle mass, depletion is cited in post-COVID-19 patients (4). The ultrasonographic study of quadriceps muscle thickness in COVID-19 patients admitted to the ICU demonstrated that the muscle wasting and decreased muscle strength occurred early and rapidly during 10 days of ICU stay (10). Bioimpedance analysis (BIA) is another useful tool to estimate body composition and fractionation of body weight into lean mass, body fat, and water (11).

Besides musculoskeletal impairment, central and peripheral neuroinvasion by SARS-CoV-2 causing anosmia and ageusia, as well as the sensory alteration in the pharynx, favors swallowing problems (12). Also, post-ICU patients, in general, present swallowing dysfunction related to prolonged intubation (> 48 h), tracheostomy, or nasogastric tube (13). A study conducted with 101 ICU patients diagnosed with COVID-19 showed that dysphagia after extubation was common in ICU patients with COVID-19 and also at ICU discharge. The study also demonstrated that patients with COVID-19 remained intubated longer and needed fewer swallowing rehabilitation sessions to return to safe oral feeding (14).

The implications of COVID-19 on swallowing muscles are still unclear. Thus, it becomes pertinent to highlight that in ICU patients without COVID-19, the electromyographic activity of the suprahyoid region after speech therapy demonstrated increased neuromuscular recruitment and improved function (15). It is believed that peripheral myopathy arising from the musculoskeletal and neuronal impairment of COVID-19, could also comprise the skeletal muscles of the head and neck. Furthermore, it is suggested that patients with higher severity of COVID-19 disease may be more likely to develop sarcopenia, the altered myoelectric activity of the suprahyoid region, and deglutition.

In this sense, after the acute phase of the disease, about 16% of patients who were hospitalized present loss of muscle mass and strength after 3 months of hospital discharge, and 4% of these after 6 months (16). However, to the best of our knowledge, there are no studies that evaluated the myoelectric activity of swallowing in post-COVID-19 patients. Based on the assumption that the healthcare workers need to be vigilant about the persistence of musculoskeletal disorders after recovery from acute illness (17) and considering the clinical demand of post-COVID-19 patients for multi-professional rehabilitation, to understanding the peripheral muscle condition, investigate the prevalence of sarcopenia, and its association with swallowing is fundamental.

Therefore, the aim of this study was to investigate the prevalence of sarcopenia and its association with myoelectric activity of the SH region in post-COVID-19 patients, stratified by disease severity and gender.

MATERIALS AND METHODS

A cross-sectional study was conducted at the post-COVID-19 Outpatient Rehabilitation Unit Rehabilitation of University Hospital of Santa Maria, Rio Grande do Sul, Brazil. The study was approved by the ethics committee (CAAE 42610921.2.0000.5346 – Date of approval: February 05, 2021) and performed in accordance with the Declaration of Helsinki. The STROBE guidelines were used to ensure the reporting of this observational study. The sample consisted of 50 patients of both genders, aged over 18 years, who were admitted to the ICU COVID-19 of the same hospital and were referred from the Pulmonology Service to the post COVID-19 Outpatient Rehabilitation Unit of the same hospital. We included patients who were referred from April to September 2021, with a minimum time between hospital discharge and outpatient evaluation of 30 days and agreed to participate by signing a consent form. Patients with neurological impairment, difficulty standing without support or amputation, tracheostomy, gastrostomy, and stage 3 hypertension (systolic blood pressure at rest >

180 mmHg and/or diastolic blood pressure at rest > 110 mmHg), which precluded the performance of deglutition, muscle electrical activity, body composition, and muscle architecture assessments, were excluded.

Participants

The individuals eligible for the research were submitted to a series of evaluations with speech therapists and physical therapists, members of the research group, previously trained to conduct the protocols, and blinded to the study outcomes. The order established for the evaluations was: deglutition assessment, peripheral muscle strength, quadriceps femoris muscular ultrasound, BIA, and electromyographic. Demographic (age, sex, and body-mass index (BMI)), clinical (COVID-19–associated symptoms at onset and preexisting medical comorbidities), and hospitalization (intensive care unit admission, duration of IMV and of hospital stay and chest CT scan at admission) data were collected from eletronic health record. Patients also underwent physical examination and assessment of the pulmonary function at the outpatient pneumology clinic. We followed the WHO (2020) (1) classification to stratify the sample by disease severity (Critical-COVID or Severe-COVID). Two groups of patients were included in the study:

1. Critical-COVID: patients surviving COVID-19 that required > 24 h of invasive mechanical ventilation (IMV) via endotracheal tube.
2. Severe-COVID: patients recovering from COVID-19 that required an acute hospitalization and supplemental oxygen (high-flow nasal cannula, venturi mask, and/or nasal cannula).

Data collection procedures

Swallowing assessment

The risk of dysphagia and swallowing evaluation was assessed using the Dysphagia Risk Evaluation Protocol (PARD). The swallowing was classified as normal (level 1), functional (level 2), mild dysphagia (level 3), mild-moderate dysphagia (level 4), moderate dysphagia (level 5), severe moderate dysphagia (level 6) and severe dysphagia (level 7) (18).

Peripheral muscle strength

The handgrip strength (HGS) was checked on the dominant hand using a hydraulic dynamometer (Saehan, SaehanCorporation, 973, Yangdeok-Dong, Masan 630-728, Korea), duly calibrated. To perform the test the individual remained seated, arm adducted parallel to the trunk and shoulder in neutral rotation, with the elbow flexed at 90°. The individual exerted maximum force to bring the two rods of the device closer to the evaluator's voice command, receiving incentive phrases for six seconds. Three maneuvers were performed with a one-minute rest interval between them, and the highest score was chosen. The HGS values below the 30th percentile of the reference adjusted for age and sex, obtained in the Brazilian population (19) were considered muscle strength loss. Also, the percentage of muscle strength loss was calculated by the dominant HGS prediction equation proposed by Novaes *et al.* (20).

Peripheral muscle mass

To measure muscle mass, another musculoskeletal variable, BIA was performed using body composition analyzer (BIA: Tanita BC601 Inner Scan® - Tanita Corp., Tokyo, Japan) with contact electrodes for the subject's feet and hands, in the vertical position. The patient was previously instructed not to consume diuretic drugs, alcoholic beverages, and caffeine, not to practice intense physical exercises, to sleep at least seven hours or to rest five to ten minutes before the evaluation, to fast for at least three hours, and to empty the bladder before the exam. Fat-free lean mass depletion was calculated according to the Appendicular Skeletal Muscle Mass Index (ASMI) (limb lean mass/height^2) with values less than 6.76 kg/m^2 for women and less than 10.76 kg/m^2 for men (21).

The assessment of quadriceps femoris muscle thickness (QFMT) was performed from ultrasound images obtained by a high-resolution device (Mindray ultrasound, DP-2200 portable, China), in B mode, with a micro convex echocardiographic transducer, 65C15EA 5.0-9.0 MHz, 4W) by a previously trained professional. The patient was positioned in dorsal decubitus, with the headboard elevated 30°, lower limbs extended, relaxed, and in a neutral position. The gel-covered transducer was positioned perpendicular to the skin, with minimal pressure (muscle and subcutaneous fat can be easily compressed), at the midpoint of the quadriceps femoris (the region between the anterosuperior iliac spine and the superior pole of the patella). The QFMT was visualized between the superior aponeurosis of the rectus femoris and the cortex of the femur. The image analysis was performed in ImageJ® software (NIH, Bethesda, MD, USA).

Assessment of sarcopenia

A sarcopenia diagnosis was confirmed by the presence of of low muscle quantity or quality. For the study, we considered any loss of muscle strength by the research criteria, associated with loss of muscle mass by ASMI (21).

Evaluation of the myometrial activity of the suprahyoid region

The electrical activity of the muscles of the right and left suprahyoid region was captured by a portable Miotool electromyograph, Miotec® brand, which used 2 channels. The signals were acquired with electrical isolation of 5000 volts, 14-bit resolution, and 2000 samples/second/channel, with a 20Hz high-pass and 500Hz low-pass filter.

For the capture of the electromyographic recordings, we followed the recommendations of SENIAN (22). The skin was sanitized with cotton soaked in 70° ethyl alcohol in the region of the muscles to be studied. When necessary, trichotomy was performed in the region. To avoid electromagnetic interference during the exam, a reference electrode was positioned in the glabella region. The patient remained seated on a wooden stool and had his feet placed on a rubber mat. To place the electrodes on the suprahyoid muscles, the patients were instructed to press their tongue against the palate and the researcher identified the muscle group by palpation. Each bipolar electrode was positioned parallel to the direction of the fibers of the anterior digastric muscle, to maximize the uptake of electrical activity and minimize noise interference.

The evaluation of muscle activity was performed using electromyographic recordings of the aforementioned region, through an evaluation protocol of swallowing electromyographic activity:

- Test 1 - Resting: for the collection of the signal at rest, the volunteer was instructed to swallow the saliva and then not to move the tongue any further, not to clench the teeth, nor swallow; close the eyes and remain as still as possible for 15 seconds. Ten seconds of the best signal were used.
- Test 2 - Maximum voluntary contraction (MVC): to perform the MVC test of the DS and SS muscles, the volunteer was instructed to place the tongue against the palate, keeping the contraction as strong as possible for seven seconds. The evaluator encouraged the action by saying, "force, force, force...relax". Five center seconds of the best signal were used.
- Test 3 - Liquid deglutition: to perform this test, the volunteer was instructed to swallow 100 ml of water continuously, but without haste, at the usual speed. The three central swallows of the best signal were used.
- Test 4 -Pasta deglutition: to perform this function, the volunteer was instructed to swallow each time the evaluator offered him/her a pasty swallow and not to talk between offers. They were offered 50 ml of medium paste (consistency prepared according to the PARD protocol), in five spoonfuls and used the three central swallows of the best signal.

For each of the tests, two to three samplings were performed, with a time interval of at least one minute of rest between them. From this collection, the signal with the best electromyographic quality was chosen based on the Fast Fourier Transform (FFT). After collecting the signal in Root Mean Square (RMS) (in the unit of microvolts), for comparisons between groups and correlations the amplitude signals were normalized by the CVM of the target muscles of the study (22).

Sample size calculation

The sample size was calculated in the G-Power 3.1 software, based on the evaluation of the first ten patients, considering a test power of 80% correlation between QFMT and body muscle mass with the myoelectric activity of the suprahyoid and a 5% error. A minimum sample size of 47 patients was required.

Data analysis

The Statistical Package for the Social Sciences software, version 20.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis, assuming a 5% significance level ($p < 0.05$). The normality of the variables was assessed by the Shapiro-Wilk test. The continuous variables are reported as a mean and standard deviation (SD) and non-parametric variables as median and minimum and maximum values. Categorical variables are presented in absolute frequencies and percentages.

In the comparisons regarding severity and gender, the Student's t-test for independent samples, Mann-Whitney U test, chi-square test, and Fisher's exact test was used, according to data distribution. The Pearson's correlation coefficient was used to evaluate associations between the quantitative variables.

RESULTS

The sample consisted of 50 patients (50.4 ± 13.35 years) classified by disease severity into two groups: Severe-COVID 31 patients (62%) and Critical-COVID 19 patients (38%), and by gender within each group. Of the total sample, 25 (50%) were female and 25 (50%) were male, with a predominant age range between 40 and 59 years. No adverse events were observed during the study.

The demographic and clinical characteristics and the risk of dysphagia of patients with COVID-19, in terms of disease severity and gender, are presented in **table I**. Patients in the Critical-COVID group had higher hospital length of stay ($p \leq 0.001$). When considering gender, male patients in the Severe-COVID group had higher hospital length of stay compared to female patients. In the clinical evaluation of the PARD protocol, the female

Table I. Clinical and demographic characteristics of the sample.

Variables	Severe COVID-19 (n = 31)			Critical COVID-19 (n = 19)			Total (n = 50)		
	Female (n = 14)	Male (n = 17)	P-value	Female (n= 11)	Male (n = 8)	P-value	Severe (n = 31)	Critical (n = 19)	P-value
Age (years)	50.2 ± 12.5	54.1 ± 15.6	0.459[a]	46.0 ± 13.0	48.6 ± 8.9	0.630[a]	52.4 ± 14.2	47.1 ± 11.2	0.218[a]
Age									
20-39, n (%)	2 (14.3)	3 (17.6)	0.800[d]	3 (27.3)	1 (12.5)	0.435[d]	5 (16.1)	4 (21.1)	0.660[b]
40 -59, n (%)	10 (71.4)	7 (41.2)	0.092[b]	7 (63.6)	6 (75.5)	0.599[b]	17 (54.8)	13 (68.4)	0.341[b]
60 -79, n (%)	1 (7.1)	6 (35.3)	0.062[d]	1 (9.1)	1 (12.5)	0.811[d]	7 (22.6)	2 (10.5)	0.282[d]
≥ 80, n (%)	1 (7.1)	1 (5.9)	0.887[d]	1 (4.0)	-	0.889[d]	2 (6.5)	-	0.252[d]
Hospitalization time (days)	8.5 (6.5 – 10.7)	12.0 (9.5 – 17.5)	0.010[c]	22.0 (16.0-43.0)	26.0 (21.0-34.7)	0.657[c]	10.0 (8.0-14.0)	23.0 (16.0 – 36.0)	< 0.001[c]
MV time (days)	-	-	-	11.0 (8.0-13.0)	12.0 (7.7-13.7)	0.717[c]	-	11.0 (8.0 – 13.0)	-
Time to assessment (days)							61.0 (47.0-96.0)	77.0 (43.0 – 89.0)	0.952[c]
Comorbidities									
SAH, n (%)	6 (42.9)	12 (70.6)	0.119[b]	14 (56.0)	4 (50.0)	0.311[b]	18 (58.1)	12 (63.2)	0.721[b]
DM, n (%)	3 (21.4)	5 (29.4)	0.613[b]	2 (18.2)	1 (12.5)	0.737[d]	8 (25.8)	3 (15.8)	0.407[b]
Obesity, n (%)	8 (57.1)	10 (58.8)	0.925[b]	8 (80.0)	5 (62.5)	0.410[b]	18 (58.1)	13 (72.2)	0.322[b]
Dyslipidemia, n (%)	4 (28.6)	5 (29.4)	0.959[b]	3 (27.3)	3 (37.5)	0.636[b]	9 (29.0)	6 (31.6)	0.849[b]
Thyroid disease, n (%)	-	1 (5.9)	0.356[d]	2 (18.2)	1 (12.5)	0.364[d]	1 (3.2)	3 (15.8)	0.112[b]
COPD, n (%)	1 (7.1)	2 (11.8)	0.665[d]	-	-	-	3 (9.7)	-	0.162[b]
PARD									
Normal deglutition, n (%)	10 (71.4)	16 (94.1)	0.087[b]	7 (63.6)	7 (87.5)	0.253[b]	26 (83.9)	14 (73.7)	0.382[b]
Functional degl, n (%)	3 (21.4)	1 (5.9)	0.199[d]	3 (27.3)	1 (12.5)	0.435[d]	4 (12.9)	4 (21.1)	0.445[b]
Mild dysphagia, n (%)	1 (7.1)	-	0.263[d]	1 (9.1)	-	0.381[d]	1 (3.2)	1 (5.3)	0.721[d]
Multiple degl Liq 5 ml	2 (14.3)	-	0.196[d]	3 (27.3)	-	0.228[d]	2 (6.5)	3 (15.8)	0.355[d]
Multiple degl. Pas 5 ml	5 (35.7)	-	0.007[d]*	4 (36.4)	1 (12.5)	0.338[d]	5 (16.2)	5 (26.3)	0.382[b]
Multiple degl Pas 10 ml	8 (57.1)	1 (5.9)	0.004 [d]*	7 (63.6)	3 (37.5)	0.370[d]	9 (29.1)	10 (5.3)	0.095[b]
Cough_Water 5 ml, n (%)	3 (21.4)	-	0.045[d]	1 (9.1)	-	0.381[d]	3 (9.7)	1 (5.3)	0.577[d]
Cough_Pas 5 ml, n (%)	2 (14.3)	-	0.107[d]	-	-	-	2 (6.5)	-	0.258[d]
Cough_Pas 10 ml, n (%)	2 (14.3)	-	0.107[d]	-	-	-	2 (6.5)	-	0.258[d]

MV: Mechanical Ventilation; SAH: Systemic Arterial Hypertension; DM: Diabetes Mellitus; COPD: Chronic Obstructive Pulmonary Disease; PARD: Dysphagia Risk Evaluation Protocol; Degl.: Deglutition; Liq: Liquid; Pas: Pasty; [a]Student's t-test for independent samples; [b]chi-square test; [c] Mann-Whitney U test; [d]Fisher's exact test; *$p < 0.05$.

Table II. Peripheral muscle status of the sample stratified by severity and gender.

Variables	Severe (n= 31)			Critical (n = 19)			Total (n = 50)		
	Female (n = 14)	Male (n = 17)	P-value	Female (n = 11)	Male (n = 8)	P-value	Severe (n = 31)	Critical (n = 19)	P-value
HGS (KgF)	25.7 ± 6.3	41.0 ± 10.8	< 0.001[a]*	20.5 ± 5.5	37.0 ± 10.0	< 0.001[a]*	34.1 ± 11.8	27.5 ± 11.2	0.079
HGS (% pred)	75.9 ± 27.6	84.4 ± 22.4	0.352	55.4 ± 16.4	71.8 ± 18.8	0.060	80.6 ± 24.8	62.3 ± 18.8	0.016[a]*
ASMI (kg/m^2)	8.0 ± 1.1	9.9 ± 1.6	< 0.001[a]*	8.1 ± 0.7	10.0 ± 0.5	< 0.001[a]*	9.0 ± 1.7	8.9 ± 1.1	0.787
QFMT (cm)	40.2 ± 8.7	42.2 ± 11.1	0.555	42.3 ± 10.9	47.6 ± 7.5	0.252	41.4 ± 9.9	44.5 ± 9.9	0.220
Sarcopenia - n (%)	-	13 (76.47)	< 0.001[b]*	-	8 (100)	< 0.001[c]*	13 (41.93)	8 (42.10)	0.990

HGS: handgrip strength; ASMI: Appendicular Skeletal Muscle Mass Index; QFMT: quadriceps femoris muscle thickness; [a]Student's t-test for independent samples; [b]chi-square test; [c]Mann-Whitney U test; *$p < 0.05$.

Table III. Myoelectric activity of the suprahyoid region of the sample stratified by severity and gender.

Variables	Severe (n = 31)			Critical (n = 19)			Total (n = 50)		
	Female (n = 14)	Male (n = 17)	P-value	Female (n = 11)	Male (n = 8)	P-value	Severe (n = 31)	Critical (n = 19)	P-value
Rest									
RS	5.4 ± 2.6	3.5 ± 2.3	0.040[a]*	5.7 ± 3.4	3.5 ± 1.8	0.114[a]	4.4 ± 2.6	4.8 ± 3.0	0.839[a]
LS	5.0 ± 2.1	3.1 ± 1.7	0.010[a]*	6.4 ± 4.6	3.3 ± 1.9	0.086[a]	4.0 ± 2.1	5.1 ± 3.9	0.447[a]
MVC									
RS	102.6 ± 46.0	110.2 ± 23.3	0.557[a]	133.9 ± 54.4	112.8 ± 19.3	0.315[a]	106.7 ± 34.9	124.5 ± 42.8	0.214[a]
LS	109.2 ± 46.5	120.9 ± 51.2	0.539[a]	140.9 ± 55.9	106.7 ± 11.2	0.109[a]	116.0 ± 48.7	126.5 ± 45.7	0.111[a]
PASTY degl.									
RS	66.2 ± 29.3	38.7 ± 19.1	0.004[a]*	59.8 ± 27.7	48.6 ± 19.1	0.373[a]	51.1 ± 27.5	55.0 ± 26.1	0.273[a]
LS	71.6 ± 37.6	38.1 ± 14.6	0.002[a]*	62.4 ± 25.0	48.1 ± 33.0	0.296[a]	53.2 ± 31.8	56.4 ± 28.7	0.249[a]
LIQUID degl.									
RS	43.9 ± 25.6	33.2 ± 12.3	0.137[a]	51.9 ± 30.5	42.6 ± 29.4	0.512[a]	38.0 ± 19.8	48.0 ± 29.6	0.923[a]
LS	41.0 (21.8-59.4)	31.4 (20.9-36.1)	0.103[c]	53.3 (28.1-75.6)	27.8 (24.4-48.3)	0.238[c]	34.0 (22.1-48.6)	30.1 (27.3-69.5)	0.460[c]
Liquid degl. n	9.0 ± 1.7	8.5 ± 3.4	0.637[a]	10.9 ± 3.1	8.8 ± 1.2	0.103[a]	8.8 ± 2.7	10.0 ± 2.6	0.337[a]
Liquid degl. time	19.4 ± 6.8	14.1 ± 5.7	0.025[a]*	20.5 ± 10.3	14.5 ± 3.3	0.134[a]	16.5 ± 6.7	18.0 ± 8.5	0.874[a]

RS: Right Suprahyoid Region; LS: Left Suprahyoid Region; MVC: Maximum Voluntary Contraction; Degl.: deglutition; [a]Student's t-test for independent samples; [b]chi-square test; [c]Mann-Whitney U test; *$p < 0.05$.

gender in the Severe-COVID group presented multiple swallows in the pasty consistency (5 and 10 ml) and coughing when degluting liquid (5 ml).

Of the total sample 14.3% reported a feeling of food stuck in the throat, 18.4% need to force to swallow solids and 10.2% were forced to deglute liquids.

Table II shows the variables of peripheral muscle condition in post-COVID-19 patients. Critical-COVID group had significantly lower HGS than predicted when compared to Severe-COVID group. When comparing gender, all patients showed reduced muscle strength compared to predicted, but male patients had significantly higher values. Considering the normative values (18), patients of both genders in the Critical-COVID group had muscle strength loss. As for the ASMI, male patients had higher values than females and showed loss of mass. Thus, only male patients were classified as sarcopenic.

The electrical activity of the right and left suprahyoid region, at rest, VLC, and during deglutition of liquid and pasty is provided in **table III**. It is noteworthy that only in the analysis in the Severe-COVID group, females showed a higher electrical activity at rest and during the deglutition of pasty foods from the suprahyoid muscles, as well as during the liquid deglutition time (100 ml).

We found a correlation between variables of peripheral muscle condition and myoelectric activity of the SH region only in the Severe-COVID group (**figure 1**). Moderate negative correlations were demonstrated between HGS and resting SD (r = -0.39, p = 0.02), HGS and pasty swallow SD (r = -0.35, p = 0.05), and HGS and pasty swallow SE (r = -0.37, p = 0.03), also moderate negative correlations between QFMT and liquid swallowing time (r = -0.41, p = 0.01) and QFMT and number of liquid swallows (r = -0.38, p = 0.03), and moderate positive correlations between QFMT and CVM SD (r = 0.37, p = 0.03).

Regarding gender, intra-group correlations were also significant in male patients in the Severe-COVID group (**figure 2**). The male gender showed a strong negative correlation between FPP and myoelectric activity of the right suprahyoid region at rest (r = -0.582, p = 0.014), QFMT and number (r = -0.539, p = 0.026) and time of liquid swallowing (r = -0.592, p = 0.012). In addition, a strong positive correlation between QFMT and CVM of the right suprahyoid region (r = 0.510, p = 0.037) and ASMI and CVM of the right suprahyoid region (r = -0.541, p = 0.025) was observed.

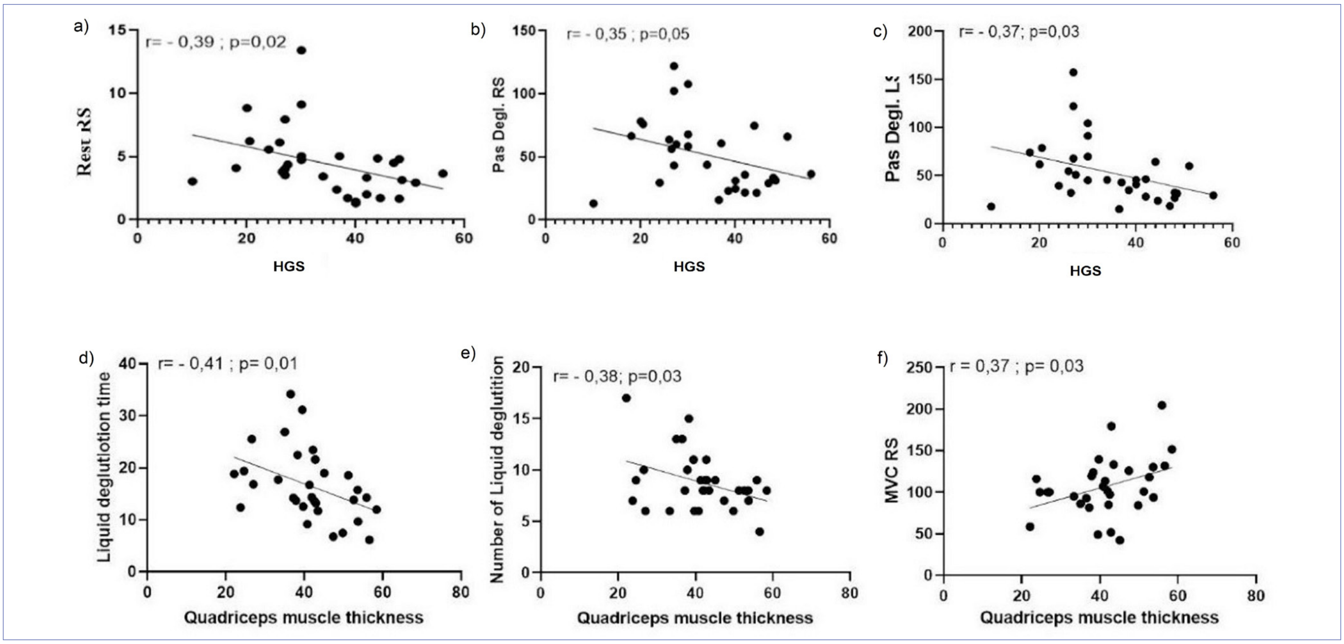

Figure 1. Correlations between peripheral muscle condition and myoelectric activity of the suprahyoid region in the Severe-COVID group.

(a) Handgrip strength (HGS) × Myoelectric activity at rest of the right suprahyoid region (RS); **(b)** Handgrip strength (HGS) × Myoelectric activity in Slurry Deglutition of the right suprahyoid region (Pas Degl. RS); **(c)** Handgrip strength (HGS) × Myoelectric activity in Slurry Swallowing of the left suprahyoid region (Pas Degl. LS); **(d)** Quadriceps muscle thickness × Liquid deglutiotion time (Liq Degl.); **(e)** Quadriceps muscle thickness x Number of Liquid deglutition (No. Liq Degl.); **(f)** Quadriceps muscle thickness × Maximum Voluntary Contraction of the Right Suprahyoid region (MVC RS).

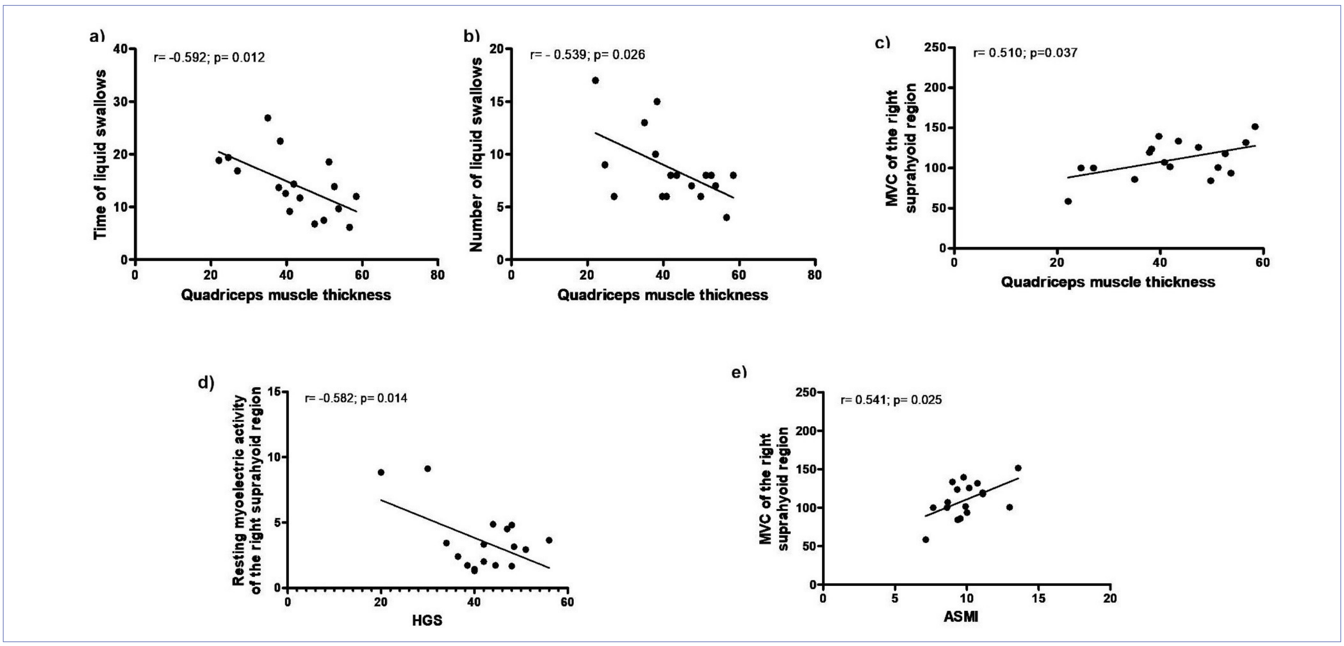

Figure 2. Correlations between peripheral muscle condition and myoelectric activity of the suprahyoid region in males in the Severe-COVID group.

(a) Time of liquid swallows × quadriceps muscle thickness; **(b)** Number of liquid swallows × quadriceps muscle thickness; **(c)** Maximum Voluntary Contraction (MVC) of the right suprahyoid region × quadriceps muscle thickness; **(d)** Resting myoelectric activity of the right suprahyoid region × Handgrip strength (HGS); **(e)** Maximum Voluntary Contraction (MVC) of the right suprahyoid region x Appendicular Skeletal Muscle Mass Index (ASMI).

DISCUSSION

This study hypothesized that patients with higher severity of COVID-19 would present greater muscle impairment, including the swallowing muscles. Patients in the Critical--COVID had higher hospital and ICU length of stay and had lower handgrip strength. However, in these patients, there was no loss of muscle mass and no change in the myoelectric activity of the SH region. In the evaluation of the risk of dysphagia, swallowing was classified as normal. Refuting, at least in part, the research hypothesis.

The production of pro-inflammatory cytokines and reactive oxygen species, resulting from immobility, accelerates skeletal muscle atrophy by proteolysis. The loss of contractile protein and fiber size are some of the components of the reduced ability to generate force. In the COVID-19 patients, regardless of disease severity, the handgrip strength values were below the specified normative values (9). These findings were confirmed in the present study since all patients showed values below the normative values, and patients in the Critical-COVID group, the handgrip strength values were significantly lower than in Severe-COVID group.

The involvement of the musculoskeletal system are attributed to indirect effects, mainly arising from inflammatory and/or immune response, but other mechanisms can be hypothesized, such as direct damage by the virus on the endothelium or peripheral nerves (23). In this sense, it is still unclear how the effects of COVID-19 on the musculoskeletal system are mediated (23).

With regard to muscle mass, in the BIA evaluation, there was no difference between the groups. It is noteworthy that excess fat mass often hides a loss of lean mass in obese individuals (24) and obesity was frequent in our sample. In the US analysis, QFMT was also not significant. As would be expected, there are fewer studies that have measured in survivors of COVID-19 Few studies have investigated peripheral muscle ultrasonography in survivors of COVID-19. Reduced lateral vastus transverse area was predictive of hospital stay (8) and severity of clinical outcome in these patients (25). Another study showed a reduction of 2.1% per day in QFMT during 10 days of hospitalization (10).

Several risk factors for dysphagia in ICU patients (intubation, loss of muscle strength, comorbidities, and bed restriction due to prolonged hospitalization) may also be present in critically ill COVID-19 patients (26). Dysphagia was present in 28.9% of patients hospitalized for COVID-19 in the study by Dawson *et al.* (12), and at 51.7% in the study conducted by Martin-Martinez *et al*. (27). However, dysphagia was not frequent in the present study. Probably, the time between discharge and outpatient evaluation (median 77 days) and the age of the patients in the sample may have influenced the swallowing results.

The prevalence of dysphagia was significantly reduced from discharge to three months follow-up (44.8% *vs* 24.0%) in 205 COVID-19 patients, with a median age of 69 years (27). Also, severe and critical post-COVID-19 patients who were assisted by the multidisciplinary team during the hospitalization period can recover normal or near-normal swallowing function after intubation and tracheostomy (12). Thus, considering that in the ICU/COVID of the hospital in question the assistance is multidisciplinary, such aspects may justify the findings related to deglutition in our study.

Considering the gender particularities, the higher electrical activity of the muscles of the suprahyoid region in the female patients in the Severe-COVID group could be explained as a compensatory mechanism due to the lower strength and peripheral muscle mass of these patients compared to males. It should be noted that in the oral phase of deglutition the muscles of the suprahyoid region are directly involved in stabilizing the jaw and in the pharyngeal phase, in the active elevation of the hyoid bone and larynx, ensuring a safe swallow (28). In this sense, an electromyographic study of the swallowing of healthy individuals (supra and infrahyoid region), classified by age group and sex, found that the female sex presents the slowest laryngeal elevation, consistent with the longer duration of swallowing. Anatomical differences in neck length determine a shorter excursion of the hyoid, longer upper esophageal sphincter opening time, and longer oropharyngeal transit time in females (29). It is emphasized that in the presence of sarcopenia the muscle strength of the suprahyoid region may be compromised, requiring greater activation of muscle fibers to compensate for this weakness (30). However, there is no simple relationship between the electromyographic signal and muscle strength. Evidence indicates that several aspects interfere with the muscle activity of the suprahyoid region, such as head posture, dental occlusion, temporomandibular dysfunction, nasal obstruction, and stress (31). Another aspect to be considered includes the different food consistencies, which may result in a higher intensity electrical activity of the muscles in this region, with increased muscle recruitment in swallowing solid food (32).

Even before the relevance of the findings of this study, some limitations should be considered. First, although the vast majority of patients showed normal and/or functional deglutition by PARD protocol, the presence of dysphagia cannot be ruled out. This assessment tool is limited to liquid and pasty consistency, and the changes could appear in the swallowing of solids, for example. Such consistency involves greater muscle strength and the need for a more present muscle mass even for occlusal stability. Second, the use of more quantifying swallowing assessment tools, such as videofluoroscopy, is considered the gold standard in aspiration investigation. However, its use was restricted during the pandemic at the hospital in question. The third limitation would be that the muscle condition before COVID-19 of these patients was not considered.

The potential clinical practice implications of this study support the importance to evaluate the peripheral and deglutition muscle function of patients who were hospitalized for COVID-19, after recovery from acute COVID-19, considering disease severity and gender. Further studies are needed to investigate the prevalence of sarcopenia and explained its association with myoelectric activity of the SH region and also the possible influence of other factors such as the role of human leukocyte antigens (HLA) genotypes for the different rates of infection and outcomes (33) among post-COVID-19 patients. We also suggest the inclusion of the electromyography as a complementary tool to evaluate swallowing in this population.

CONCLUSIONS

In summary, post-COVID-19 critically ill patients showed a loss of muscle strength compared to what was predicted. In this group, male patients showed sarcopenia, while female patients showed only pre-sarcopenia. On the other hand, male patients in Severe-COVID group showed loss of muscle mass by bioimpedance. The association between peripheral muscle condition and myoelectric activity was demonstrated only in the Severe-COVID group, suggesting that COVID-19 may compromise the muscles involved in swallowing even in non-critical patients. It is noteworthy the evaluation of these outcomes in post-COVID-19 patients to focus on individualized rehabilitation plan to provide functional recovery after hospital discharge.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

VBB: conceptualization, design, data collection, writing – original draft. JAS: data collection, manuscript writing, writing – original draft. TDS: methods, data analysis writing – original draft. EAVA: methods. ACLD: writing – review & editing. IMA: writing – original draft, writing – review & editing. ARBS: design, supervision, writing – review & editing. ASP: design, guidance, writing – review & editing.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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