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1 **HYPERMETABOLISM IS A REALITY IN AMYOTROPHIC LATERAL**
2 **SCLEROSIS COMPARED TO HEALTHY SUBJECTS**

3 **Authors:** Philippe Fayemendy, Benoit Marin, Anaïs Labrunie, Yves Boirie, Stéphane
4 Walrand, Najate Achamrah, Moïse Coëffier, Pierre-Marie Preux, Géraldine Lautrette, Jean-
5 Claude Desport, Philippe Couratier, Pierre Jésus

6 Philippe Fayemendy, Nutrition Unit, University Hospital of Limoges, Limoges, France.
7 INSERM UMR 1094, Tropical Neuroepidemiology, Limoges, France

8 Benoit Marin, INSERM UMR 1094, Tropical Neuroepidemiology, Limoges, France. Center
9 for Epidemiology, Biostatistics and Methodology of Research, University Hospital of
10 Limoges, France

11 Anaïs Labrunie, Center for Epidemiology, Biostatistics and Methodology of Research,
12 University Hospital of Limoges, France

13 Yves Boirie, University Clermont Auvergne, INRA, UNH, Human Nutrition Unit, CRNH
14 Auvergne, Clermont-Ferrand, France

15 Stéphane Walrand, University Clermont Auvergne, INRA, UNH, Human Nutrition Unit,
16 CRNH Auvergne, Clermont-Ferrand, France

17 Najate Achamrah, INSERM UMR 1073, Normandie University, Rouen, France

18 Moïse Coëffier, INSERM UMR 1073, Normandie University, Rouen, France

19 Pierre-Marie Preux, INSERM UMR 1094, Tropical Neuroepidemiology, Limoges, France.
20 Center for Epidemiology, Biostatistics and Methodology of Research, University Hospital of
21 Limoges, France

22 Géraldine Lautrette, ALS center, University Hospital of Limoges, France

23 Jean-Claude Desport, Nutrition Unit, University Hospital of Limoges, Limoges, France.

24 INSERM UMR 1094, Tropical Neuroepidemiology, Limoges, France

25 Philippe Couratier, ALS center, University Hospital of Limoges, France. INSERM UMR

26 1094, Tropical Neuroepidemiology, Limoges, France

27 Pierre Jésus, Nutrition Unit, University Hospital of Limoges, Limoges, France. INSERM

28 UMR 1094, Tropical Neuroepidemiology, Limoges, France

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37 **Corresponding author:** Dr. Philippe Fayemendy, Nutrition Unit, University Hospital, 2

38 Avenue Martin Luther King, 87042 Limoges cedex.

39 philippe.fayemendy@chu-limoges.fr *Phone:* + 33 5 55 05 66 21

40

41 **Authors' contribution:**

42 PF, PJ, PC, JCD and BM designed research; PJ, PF, YB, SW, MC, PC and JCD conducted
43 research; PJ, PF, YB, SW, MC and JCD provided essential materials (databases); AL, PJ and
44 PF performed statistical analysis; PF, PJ, AL, PC, JCD wrote paper; PF and PJ had primary
45 responsibility for final content. All authors read and approved the final manuscript.

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52 **Abbreviations**

53 ALS: amyotrophic lateral sclerosis

54 BMI: body mass index

55 CI: confidence interval

56 FM: fat mass

57 FFM: free fat mass

58 IC: indirect calorimetry

59 IQR: interquartile range

60 cREE: calculated resting energy expenditure

61 mREE: measured resting energy expenditure

62 REE: resting energy expenditure

63 RQ: respiratory quotient

64 TEE: total energy expenditure

65 **Abstract:**

66 Rationale: Hypermetabolism (HM) in Amyotrophic lateral sclerosis (ALS) is the reflection of
67 a high energy metabolic level, but this alteration seems controversial. The main objective of
68 the study was to confirm the existence of HM during ALS compared to healthy subjects.

69 Methods: A cohort of ALS patients was compared to a control group without metabolic
70 disorder. The assessment included anthropometric criteria measurements, body composition
71 by bioelectric impedance analysis and resting energy expenditure (REE) by indirect
72 calorimetry. HM was defined as a variation $> +10\%$ between measured and calculated REE.
73 Statistical analysis used Mann-Whitney and Chi2 tests. Multivariate analysis included logistic
74 regression.

75 Results: 287 patients and 75 controls were included. The metabolic level was higher in ALS
76 patients (1500 kcal/24h [1290–1693] vs. 1230 kcal/24h [1000 –1455], $p < 0.0001$) as well as
77 the REE/fat free mass ratio (33.5 kcal/kg/24h [30.4 –37.8] vs. 28.3 kcal/kg/24h [26.1–33.6], p
78 < 0.0001). 55.0% of ALS patients had HM vs. 13.3% of controls ($p < 0.0001$). HM was
79 strongly and positively associated with ALS (OR= 9.50 [4.49 –20.10], $p < 0.0001$).

80 Conclusions: HM in ALS is a reality, which affects more than half of the patients and is
81 associated with ALS. This work confirms a very frequent metabolic deterioration during ALS.
82 The identification of HM can allow a better adaptation of the patients' nutritional intake.

83 **Keywords:** Amyotrophic lateral sclerosis, hypermetabolism, resting energy expenditure

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89 **INTRODUCTION**

90 Amyotrophic lateral sclerosis (ALS) is a rare and severe neurodegenerative disease
91 commonly diagnosed between the age of 65 to 70 years and whose incidence is 2 to 3 /
92 100,000 person-years (1–5). Weight loss during ALS is associated with impaired functional
93 status and quality of life (6,7). Undernutrition affects 9 to 55% of patients (7–10) and is an
94 independent negative factor for survival (6). Undernutrition in ALS results from an
95 imbalance between energy intake and total energy expenditure (TEE) (11,12). The resting
96 energy expenditure (REE), component of the TEE, can be increased in ALS, and this increase
97 corresponding if high, to hypermetabolism (HM) (7,13). HM is a persistent phenomenon
98 during the course of the disease (14), and would concern 50 to 60% of patients (7,13). Only
99 two studies, with a modest number of cases and a heterogeneous methodology, studied HM in
100 ALS compared to a control group (13,15). Due to the disparate results of these works, the
101 notion of HM in ALS is controversial.

102 In light of this controversy, the main objective of this study was to confirm the existence of
103 HM during ALS compared to healthy subjects.

104

105 **METHODS**

106 **Inclusion criteria**

107 ALS patients included were followed up at the ALS Referral Centre and the Nutrition Unit of
108 the University Hospital of Limoges (France), diagnosed between November 1996 and
109 November 2014, according to Airlie House criteria (16). They were suffering from ALS alone

110 or associated with frontotemporal dementia and all were treated with riluzole. They could
111 have a bulbar or limb onset form, a familial background (FALS) or sporadic form of ALS.
112 Functional impairment was assessed by the ALS Functional Rating Scale (ALSFRS) or its
113 revised form (ALSFRS-R) (17). REE was measured (mREE) by indirect calorimetry (IC),
114 with a respiratory quotient (RQ) between 0.7 and 0.87 (7). Indeed, during an overnight fasting
115 period from 7 to 14 hours, the RQ would be 0.68 to 0.90 (18). IC was performed less than 12
116 months after diagnosis and less than 1.5 months after the nutritional assessment. The body
117 composition was to be assessed by bioelectric impedance analysis (BIA), using the validated
118 formula for ALS patients (19).

119 The control subjects, from the Human Nutrition Unit of the University of Clermont Auvergne
120 (France), were healthy people without ALS and not suffering from a metabolic altering
121 disease such as inflammatory bowel disease, cancer, dysthyroidism or infectious disease.
122 Controls were assessed by IC and BIA, according to similar procedures to those used for
123 patients, using Kyle et al. equation for the body composition determination (20,21).

124 **Nutritional and metabolic assessment**

125 The nutritional and metabolic assessments, homogeneous and standardized in both centres,
126 were performed according to standard procedures. Subjects were weighed in their underwear
127 using a SECATM electronic scale recording to 0.1 kg (Vogel & Halke, Hamburg, Germany) in
128 an upright position or on a SECATM weighing chair if they could not stand upright. Height
129 was obtained using a SECATM gauge recording to 0.2 cm (Vogel & Halke, Hamburg,
130 Germany) in an upright position, or using the Chumlea formulas for people over 60 who
131 could not be verticalized (22). Body mass index (BMI) was calculated as weight (kg) / height
132 x height (m²). Fat free mass (FFM in kg) and fat mass (FM in kg) were obtained from
133 bioelectric impedance analysis at 50 kHz after five minutes of rest in supine position. They

134 were calculated using validated formulas: Desport et al. equation for ALS patients (19) with
135 an AnalycorTM device (Eugédia, Chambly, France), and Kyle et al. equation (21) for controls
136 with BIA 101TM (RJL System, Detroit, USA). The triceps skinfold (TSF), necessary for the
137 FFM determination according to the Desport et al. formula (19), was obtained from the
138 average of three measurements on each side with a Harpenden caliper (Baty International,
139 Burgess Hill, UK) according to the usual modalities (23).

140 IC was performed in the morning after 12 hours overnight fasting in supine position and at
141 rest, using the Quark RMRTM (Cosmed, Rome, Italy) and the Deltatrac IITM device
142 (DatexEngström, Helsinki, Finland), after instruments calibration (24). The mean
143 repeatability coefficient was 7,3 +/- 2%. Harris and Benedict 1919 (HB1919) formulas were
144 used to calculate REE (cREE) (22). The percentage of REE variation (Δ REE) was calculated
145 using the formula: Δ REE = (mREE [kcal / 24h] - cREE [kcal / 24h]) / cREE (kcal / 24h) *
146 100. HM was defined as Δ REE > +10%.

147 **Data collection and Statistical analysis**

148 All data were collected prospectively and extracted from the CleanWEBTM database of the
149 Limoges ALS Referral centre and from the Human nutrition Unit Laboratory of Clermont-
150 Ferrand databases, validated by the French Commission Nationale de l'Informatique et des
151 Libertés. All subjects gave their informed consent for the data collection. The study was
152 reported at ClinicalTrials.gov (ClinicalTrials.gov Identifier: NCT03382392).

153 Statistical analysis was performed using SASTM 9.3 (SAS institute NC, Cary, USA).
154 Comparative analyses were conducted on the ALS group versus the control group using the
155 Mann-Whitney and the Chi2 tests. To investigate the factors associated with HM, a logistic
156 regression model was conducted and results were expressed with odds ratio (OR) and 95%
157 confidence interval (95%CI). Adjustment variables were sex, age, BMI, FFM and FM.

158 Covariates with a significance threshold $p < 0.2$ in univariate analysis were included in
159 multivariate analysis and a forward selection variable was used.

160

161 **RESULTS**

162 IC was performed on 405 ALS patients of which 118 were excluded: 35 for a RQ < 0.7 or $>$
163 0.87 , 30 for a time lag between IC and nutritional assessment greater than 1.5 months, 25
164 because the delay between diagnosis and IC was over 12 months and 28 because of a lack of
165 BIA data (figure 1).

166 Seventy-five healthy controls were compared to 287 ALS patients. In ALS patients, 40.8 %
167 had a bulbar form, and 9.4% a familial form. The median delay between diagnosis and
168 nutritional assessment was 4.2 month [2.2–6.4]. The median ALSFRS-R score at inclusion
169 was 39.6 points [35-43]. Characteristics and comparisons of ALS patients and controls are
170 presented in table 1. The RQ was not significantly different between the two populations. The
171 metabolic level was higher in ALS patients (1500 kcal/24h [1290–1693] vs. 1230 kcal/24h
172 [1000 –1455], $p < 0.0001$) as well as REE/FFM (33.5 kcal/kg/24h [30.4 –37.8] vs. 28.3 [26.1–
173 33.6] kcal/kg/24h, $p < 0.0001$). HM was significantly more frequent in ALS patients than in
174 controls (55.0% vs. 13.3%, $p < 0.0001$).

175 HM was not found in 129 patients (45,0%) and 65 controls (86,7%). In subjects not
176 considered to be hypermetabolic, mREE was significantly higher in ALS patients compared
177 to healthy controls (1331 kcal/24h [1153 –1543] vs. 1210 kcal/24h [981 –1450]), $p = 0.0008$)
178 with a higher REE variation (1.8% [-3.5 –6.1] vs. -2.1% [-8.8 –1.4], $p = 0.0001$). In the
179 absence of HM, REE/ FFM ratio was higher in ALS patients (31.0 kcal/kg/24h [28.0 –35.0]
180 vs. 28.1 kcal/kg/24h [25.8 –32.8], $p = 0.0004$).

181 Factors associated with HM in univariate and multivariate analysis were presented in table 2.
182 After adjustment, HM was positively associated with ALS ($OR_{adjusted} = 9.50 [4.49 - 20.10]$, p
183 < 0.0001) and with being a male ($OR_{adjusted} = 1.73 [1.10 - 2.72]$, $p = 0.018$) (table 2).

184

185 **DISCUSSION**

186 This study highlights the existence of HM and the high level of metabolic alteration in a large
187 cohort of ALS patients compared to healthy subjects. These metabolic alterations concern all
188 patients, even in the absence of HM. It was essential for clinical practice to confirm the reality
189 of HM during ALS. Indeed, these metabolic alterations can contribute to an increase in TEE
190 (12). In the absence of adaptation of energy intake, an increase in TEE is a cause of weight
191 loss and undernutrition, which are associated with impaired functional status, alteration of
192 quality of life and decrease in survival (6,7,13). This reinforces the importance of metabolic
193 assessment and nutritional care in ALS, as soon as the diagnosis is made, in order to adapt the
194 level of dietary intake or enteral nutrition.

195 Our ALS patients sample is the largest in literature in this field. The original use of a logistic
196 regression model clearly asserts a positive and strong association between ALS and HM,
197 which has not been demonstrated previously. Indeed, Desport et al. described a higher mREE
198 in 62 ALS patients versus 31 healthy volunteers, comparable on nutritional parameters, but
199 the lack of multivariate analysis could not confirm the link between HM and ALS (13).
200 Conversely, Vaisman et al. found a decrease in mREE in a modest population of 33 ALS
201 patients compared to 33 controls: due to the disparity in weight, BMI and FFM between the
202 two groups, and the lack of adjustment on these variables, the results were not interpretable
203 (15).

204 Regardless of the relationship between HM and ALS, our study suggests a male influence on
205 HM. Although FFM, which is proportionately higher in men (20) and the main determinant of
206 REE (15,26), this relationship is not explained in this study by a difference in body
207 composition by gender. Indeed, body composition parameters were not associated with HM in
208 this work.

209 The causes of the HM remain unknown. Several hypotheses are mentioned: increased glucose
210 and lipids consumption, mitochondrial alterations, hypothalamic dysfunction (6,27). Due to
211 the high frequency of metabolic changes in ALS, HM can certainly be considered a marker of
212 the disease. The identification of metabolic pathways and the search for biomarkers of HM
213 would likely improve the understanding of physiopathological mechanisms and propose new
214 therapeutic pathways targeted at metabolic phenotype in ALS.

215 Our study presents limitations. Despite the large number of patients followed by the ALS
216 Referral center (88.2% of patients from our region) (7), the data were not extracted from a
217 register and were therefore not totally exhaustive. It would have been preferable to have a
218 larger control population from the same center and matched on the patients. We did not have
219 such a control cohort in our center, and we used the control population which seemed to us
220 the most suitable. So, even if patients and controls were assessed in two different centers and
221 regions, these bordering regions (Limousin and Auvergne) had a comparable gender and age
222 distribution ratio according to the French National Institute of Statistics (28). Moreover,
223 nutritional and metabolic assessments were performed under standardized conditions in both
224 center, and body composition was obtained from crude impedancemetric data (impedance and
225 reactance), using validated formulas for each group: Desport et al. formula for ALS patients,
226 validated versus the reference method (Dual x-ray absorptiometry) (19) and Kyle et al.
227 formula for controls, suitable for body composition assessment in elderly subjects (21). Due
228 to the unavailability of the same device in each center, two different devices were used for IC.

229 However, the mREE values of its two devices were recognized as very similar in a previous
230 work (29). Even if age and BMI were different between patients and controls, we have taken
231 into account these variances, which have been minimized by adjustment in multivariate
232 analysis. We chose not to consider the subtype of ALS (clinical phenotype; familial versus
233 sporadic form), the fasciculations and the tobacco consumption for adjustment, since previous
234 works found no influence for these criteria on the metabolic changes (6,7,13). Finally, even if
235 autonomic nervous abnormalities with a potential influence on the metabolic level were
236 described in ALS, manifested for example by an increase in blood pressure or resting heart
237 rate (30,31), we did not have such data to make an adjustment.

238 The use of HB1919 formulas, established for healthy subjects, can be another bias. Indeed, it
239 is possible that the Δ REE demonstrated was related to an inappropriate use of these equations
240 in ALS patients. Nevertheless, in a recent work, Jesus et al. compared the mREE and cREE
241 by 12 predictive formulas, including HB1919 equations (32): This work highlighted that ALS
242 patients had a mREE higher than cREE whatever the formula used, and therefore that the
243 increase in REE was not related to the inappropriate use of HB1919 equations. Thus, these
244 formulas seem to be relevant as a reference value to search for an Δ REE. Furthermore, other
245 authors have validated, for ALS patients, the use of equations comprising sex and age, such as
246 HB1919 or Mifflin-St Jeor formulas, both for the REE measurement (33), but also in models
247 allowing to estimate the TEE (12).

248 Our study focused specifically on the REE assessment, which is not sufficient on its own to
249 define the energy requirements of patients. We didn't studied the TEE, which is a basis for
250 estimating energy requirements. Thus, in a previous work, Kasarskis et al. proposed models
251 for estimating the TEE, which can be used in current practice, taking into account body
252 composition and physical function, making it possible to adapt food or enteral intakes (12).

253 At last, this study cannot specify when the metabolic changes appear. It could be of interest to
254 measure REE in the presymptomatic stage in descendants of ALS familial form patients, in
255 order to detect a possible HM before onset of the first symptoms and to set up early
256 nutritional care.

257

258 **CONCLUSION**

259 The concept of HM during ALS is a reality and could not be controversial: HM affects more
260 than half of the patients and is positively and strongly associated with ALS. This work
261 confirms a very frequent metabolic alteration during ALS, contributing to the deterioration of
262 nutritional status, a factor of poor prognosis. This reinforces the importance of HM screening,
263 which should be systematic, to provide early and appropriate nutritional care: diet advice, oral
264 supplementation or enteral nutrition. The causes of HM are still unknown. The identification
265 of the mechanisms involved could improve patient management.

266

267 **Conflicts of interest**

268 The authors have no conflict of interest to disclose

269 **References**

- 270 1. Marin B, Hamidou B, Couratier P, Nicol M, Delzor A, Raymondeau M, et al.
271 Population-based epidemiology of amyotrophic lateral sclerosis (ALS) in an ageing
272 Europe – the French register of ALS in Limousin (FRALim register). *Eur J Neurol.*
273 2014;21:1292-300. <https://doi.org/10.1111/ene.12474>

- 274 2. Logroscino G, Traynor BJ, Hardiman O, Chio A, Mitchell D, Swingler RJ, et al.
275 Incidence of amyotrophic lateral sclerosis in Europe. *J Neurol Neurosurg Psychiatry*.
276 2010;81:385–90. <http://dx.doi.org/10.1136/jnnp.2009.183525>
- 277 3. Marin B, Boumédiene F, Logroscino G, Couratier P, Babron M-C, Leutenegger AL, et
278 al. Variation in worldwide incidence of amyotrophic lateral sclerosis: a meta-analysis.
279 *Int J Epidemiol*. 2017;46:57-74. <https://doi.org/10.1093/ije/dyw061>
- 280 4. Marin B, Logroscino G, Boumédiene F, Labrunie A, Couratier P, Babron M-C, et al.
281 Clinical and demographic factors and outcome of amyotrophic lateral sclerosis in
282 relation to population ancestral origin. *Eur J Epidemiol*. 2016 Mar 1;31:229–45.
283 <https://doi.org/10.1007/s10654-015-0090-x>
- 284 5. Marin B, Arcuti S, Jesus P, Logroscino G, Copetti M, Fontana A, et al. Population-
285 Based Evidence that Survival in Amyotrophic Lateral Sclerosis Is Related to Weight
286 Loss at Diagnosis. *Neurodegener Dis*. 2016;16:225–34.
287 <https://doi.org/10.1159/000442444>
- 288 6. Jésus P, Fayemendy P, Nicol M, Lautrette G, Sourisseau H, Preux P-M, et al.
289 Hypermetabolism is a deleterious prognostic factor in patients with amyotrophic
290 lateral sclerosis. *Eur J Neurol*. 2018;25:97-104. <https://doi.org/10.1111/ene.13468>
- 291 7. Jésus P, Marin B, Fayemendy P, Nicol M, Lautrette G, Sourisseau H, et al. Resting
292 energy expenditure equations in amyotrophic lateral sclerosis, creation of an ALS-
293 specific equation. *Clin Nutr*. 2019;38:1657-65.
294 <https://doi.org/10.1016/j.clnu.2018.08.014>
- 295 8. Desport JC, Preux PM, Truong TC, Vallat JM, Sautereau D, Couratier P. Nutritional
296 status is a prognostic factor for survival in ALS patients. *Neurology*. 1999;53:1059-63.
297 <https://doi.org/10.1212/WNL.53.5.1059>

- 298 9. Marin B, Desport JC, Kajeu P, Jesus P, Nicolaud B, Nicol M, et al. Alteration of
299 nutritional status at diagnosis is a prognostic factor for survival of amyotrophic lateral
300 sclerosis patients. *J Neurol Neurosurg Psychiatry*. 2011;82:628-34.
301 <http://dx.doi.org/10.1136/jnnp.2010.211474>
- 302 10. Genton L, Viatte V, Janssens J-P, Héritier A-C, Pichard C. Nutritional state, energy
303 intakes and energy expenditure of amyotrophic lateral sclerosis (ALS) patients. *Clin*
304 *Nutr*.2011;30:553-9. <https://doi.org/10.1016/j.clnu.2011.06.004>
- 305 11. Kasarskis EJ, Mendiondo MS, Wells S, Malguizo MS, Thompson M, Healey M, et al.
306 The ALS Nutrition/NIPPV Study: design, feasibility, and initial results. *Amyotroph*
307 *Lateral Scler* 2011;12:17-25. <https://doi.org/10.3109/17482968.2010.515225>
- 308 12. Kasarskis EJ, Mendiondo MS, Matthews DE, Mitsumoto H, Tandan R, Simmons Z, et
309 al. Estimating daily energy expenditure in individuals with amyotrophic lateral
310 sclerosis. *Am J Clin Nutr*. 2014;99:792-803. <https://doi.org/10.3945/ajcn.113.069997>
- 311 13. Desport JC, Preux PM, Magy L, Boirie Y, Vallat JM, Beaufrère B, et al. Factors
312 correlated with hypermetabolism in patients with amyotrophic lateral sclerosis. *Am J*
313 *Clin Nutr*. 2001;74:328–34. <https://doi.org/10.1093/ajcn/74.3.328>
- 314 14. Bouteloup C, Desport J-C, Clavelou P, Guy N, Derumeaux-Burel H, Ferrier A, et al.
315 Hypermetabolism in ALS patients: an early and persistent phenomenon. *J Neurol*.
316 2009;256:1236-42. <https://doi.org/10.1007/s00415-009-5100-z>
- 317 15. Vaisman N, Lusaus M, Nefussy B, Niv E, Comaneshter D, Hallack R, et al. Do
318 patients with amyotrophic lateral sclerosis (ALS) have increased energy needs? *J*
319 *Neurol Sci*. 2009;279:26-9. <https://doi.org/10.1016/j.jns.2008.12.027>
- 320 16. Brooks BR, Miller RG, Swash M, Munsat TL, World Federation of Neurology
321 Research Group on Motor Neuron Diseases. El Escorial revisited: revised criteria for
322 the diagnosis of amyotrophic lateral sclerosis. *Amyotroph Lateral Scler Mot Neuron*

- 323 Disord Off Publ World Fed Neurol Res Group Mot Neuron Dis. 2000 ;1:293–9.
324 <https://doi.org/10.1080/146608200300079536>
- 325 17. Cedarbaum JM, Stambler N, Malta E, Fuller C, Hilt D, Thurmond B, et al. The
326 ALSFRS-R: a revised ALS functional rating scale that incorporates assessments of
327 respiratory function. BDNF ALS Study Group (Phase III). J Neurol Sci. 1999;169:13–
328 21. [https://doi.org/10.1016/s0022-510x\(99\)00210-5](https://doi.org/10.1016/s0022-510x(99)00210-5)
- 329 18. Jéquier E, Felber JP. Indirect calorimetry. Baillieres Clin Endocrinol Metab.
330 1987;1:911-35. [https://doi.org/10.1016/S0950-351X\(87\)80011-3](https://doi.org/10.1016/S0950-351X(87)80011-3)
- 331 19. Desport JC, Preux PM, Bouteloup-Demange C, Clavelou P, Beaufrère B, Bonnet C, et
332 al. Validation of bioelectrical impedance analysis in patients with amyotrophic lateral
333 sclerosis. Am J Clin Nutr. 2003;77:1179–85. <https://doi.org/10.1093/ajcn/77.5.1179>
- 334 20. Kyle UG, Genton L, Slosman DO, Pichard C. Fat-free and fat mass percentiles in
335 5225 healthy subjects aged 15 to 98 years. Nutrition. 2001;17:534-41.
336 [https://doi.org/10.1016/S0899-9007\(01\)00555-X](https://doi.org/10.1016/S0899-9007(01)00555-X)
- 337 21. Genton L, Karsegard VL, Kyle UG, Hans DB, Michel JP, Pichard C. Comparison of
338 four bioelectrical impedance analysis formulas in healthy elderly subjects.
339 Gerontology. 2001;47:315-23. <https://doi.org/10.1159/000052821>
- 340 22. Chumlea WC, Roche AF, Steinbaugh ML. Estimating stature from knee height for
341 persons 60 to 90 years of age. J Am Geriatr Soc. 1985;33:116-20.
342 <https://doi.org/10.1111/j.1532-5415.1985.tb02276.x>
- 343 23. Frisancho AR. New norms of upper limb fat and muscle areas for assessment of
344 nutritional status. Am J Clin Nutr. 1981;34:2540-5.
345 <https://doi.org/10.1093/ajcn/34.11.2540>
- 346 24. Ferrannini E. The theoretical bases of indirect calorimetry: A review. Metabolism.
347 1988;37:287-301. [https://doi.org/10.1016/0026-0495\(88\)90110-2](https://doi.org/10.1016/0026-0495(88)90110-2)

- 348 25. Harris JA, Benedict FG. A Biometric Study of Human Basal Metabolism. Proc Natl
349 Acad Sci U S A. 1918;4:370-3. <https://doi.org/10.1073/pnas.4.12.370>
- 350 26. Cunningham JJ. Body composition as a determinant of energy expenditure: a synthetic
351 review and a proposed general prediction equation. Am J Clin Nutr. 1991;54:963-9.
352 <https://doi.org/10.1093/ajcn/54.6.963>
- 353 27. Dupuis L, Pradat P-F, Ludolph AC, Loeffler J-P. Energy metabolism in amyotrophic
354 lateral sclerosis. Lancet Neurol. 2011;10:75-82. [https://doi.org/10.1016/S1474-
355 4422\(10\)70224-6](https://doi.org/10.1016/S1474-4422(10)70224-6)
- 356 28. Institut national de la statistique et des études économiques (INSEE). Estimation de la
357 population au 1^{er} janvier 2020. Séries par région, département, sexe et âge de 1975 à
358 2020. <https://www.insee.fr/fr/statistiques/1893198>. Accessed 1 November 2020
- 359 29. Graf S, Karsegard VL, Viatte V, Maisonneuve N, Pichard C, Genton L. Comparison
360 of three indirect calorimetry devices and three methods of gas collection: a prospective
361 observational study. Clin Nutr. 2013;32(6):1067-72.
362 <https://doi.org/10.1016/j.clnu.2013.08.012>
- 363 30. Oey PL, Vos PE, Wieneke GH, Wokke JHJ, Blankestijn PJ, Karemaker JM. Subtle
364 involvement of the sympathetic nervous system in amyotrophic lateral sclerosis.
365 Muscle Nerve. 2002;25:402-8. <https://doi.org/10.1002/mus.10049>
- 366 31. Shimizu T. Sympathetic Hyperactivity and Sympathovagal Imbalance in Amyotrophic
367 Lateral Sclerosis. Eur Neurol Rev. 2012;8:46.
368 <http://doi.org/10.17925/ENR.2013.08.01.46>
- 369 32. Jésus P, Fayemendy P, Marin B, Nicol M, Sourisseau H, Boirie Y, et al. Increased
370 resting energy expenditure compared with predictive theoretical equations in
371 amyotrophic lateral sclerosis. Nutrition. 2020;77:110805.
372 <https://doi.org/10.1016/j.nut.2020.110805>

373 33. Ellis AC, Rosenfeld J. Which equation best predicts energy expenditure in
374 amyotrophic lateral sclerosis? J Am Diet Assoc. 2011;111:1680-7.
375 <https://doi.org/10.1016/j.jada.2011.08.002>

376

377 **Figure legend**

378 Figure 1: Flowchart of ALS patients included in the study.

379 ALS: amyotrophic lateral sclerosis; RQ: respiratory quotient

380

Figure 1:

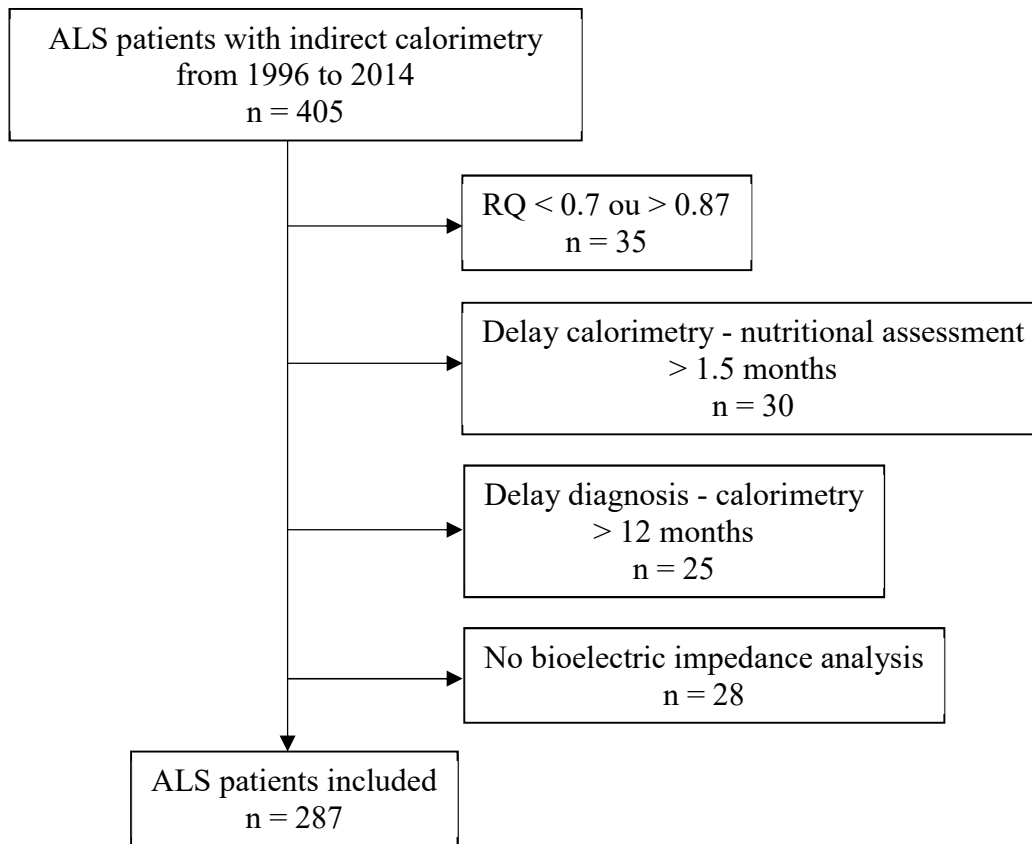


Table 1: Comparison of demographic, nutritional characteristics and resting energy expenditure (REE) between ALS patients and healthy controls

| Variables | ALS Patients | Healthy controls | p |
|--------------------------|------------------------------------|-----------------------------------|-------------------|
| | Median [IQR] or n (%) (n = 287) | Median [IQR] or n (%) (n = 75) | |
| Male | 145 (50.5) | 40 (53.3) | 0.66 |
| Age at IC (years) | 66.4 [56.7–73.1] | 75.0 [68.5–86.0] | <0.0001 |
| Weight (kg) | 64.9 [57.9 –74.2] | 66.0 [54.5 –75.0] | 0.25 |
| BMI (kg/m ²) | 24.3 [22.0 –27.5] | 26.2 [23.2 –28.4] | 0.026 |
| FFM (kg) | 44.4 [36.9 –51.8] | 40.7 [30.9 –54.8] | 0.15 |
| FM (kg) | 20.7 [15.2 –25.4] | 20.5 [16.8 –26.9] | 0.56 |
| mREE (kcal/24h) | 1500 [1290 –1693] | 1230 [1000 –1455] | <0.0001 |
| cREE (kcal/24h) | 1327 [1195 –1496] | 1262 [1023 –1460] | 0.0015 |
| Δ REE (%) | 11.5 [3.6 –19.3] | -1.2 [-7.5 –5.3] | <0.0001 |
| Hypermetabolism | 158 (55.0) | 10 (13.3) | <0.0001 |
| REE/weight (kcal/kg/24h) | 22.9 [20.9 –25.0] | 19.2 [17.4 –20.9] | <0.0001 |
| REE/FFM (kcal/kg/24h) | 33.5 [30.4 –37.8] | 28.3 [26.1–33.6] | <0.0001 |

ALS: amyotrophic lateral sclerosis; BMI: body mass index; FFM: free fat mass; cREE: calculated resting energy expenditure; Δ REE: percentage of REE variation; FM: fat mass; IC: indirect calorimetry; IQR: interquartile range; mREE: measured resting energy expenditure; n: number

Table 2: Factors associated with hypermetabolism

| Variables | Univariate analysis | | Multivariate analysis | |
|---------------------------|-----------------------------|-------------------|--------------------------------|-------------------|
| | OR _{crude} [95%CI] | p | OR _{adjusted} [95%CI] | p |
| ALS patients vs. controls | 7.96 [3.93 – 16.12] | <0.0001 | 9.50 [4.49 – 20.10] | <0.0001 |
| Male vs. female | 1.50 [0.99 – 2.28] | 0.054 | 1.73 [1.10 – 2.72] | 0.018 |
| Age (+ 1 year increment) | 0.98 [0.97 – 1.00] | 0.061 | 1.01 [0.99 ; 1.03] | 0.250 |
| BMI (+ 1 point increment) | 0.96 [0.92 – 1.00] | 0.070 | | |
| FFM (+ 1 kg increment) | 1.02 [1.00 – 1.04] | 0.064 | | |
| FM (+ 1 kg increment) | 0.97 [0.95 – 1.00] | 0.023 | | |

OR: odds ratio; CI: confidence interval; ALS: amyotrophic lateral sclerosis; BMI: body mass index;

FFM: free fat mass; FM: fat mass