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1 The physiological characteristics of an 83-year-old champion female master

2 runner

3

4 Thomas CATTAGNI¹, Vincent GREMEAUX^{2,3,4}, Romuald LEPERS⁵

- 5
- 6 ¹ Inserm Unit 1179, Team 3: Technologies and Innovative Therapies Applied to Neuromuscular
- 7 diseases, UVSQ. CIC 805, Physiology-Functional Testing Ward, AP-HP, Raymond Poincaré
- 8 Teaching Hospital, Garches, France.
- 9 ² Swiss olympic medical center, Division de médecine physique et réadaptation, CHUV, 1011
- 10 Lausanne
- ³ Institute of Sport Sciences, University of Lausanne, Lausanne, Switzerland.
- 12 ⁴ Pôle Rééducation-Réadaptation, CHU Dijon, France.
- 13 ⁵ INSERM UMR1093-CAPS, Université Bourgogne Franche-Comté, UFR des Sciences du
- 14 Sport, F-21000, Dijon
- 15

16 **Corresponding author:**

- 17 Thomas Cattagni
- 18 Hôpital Raymond Poincaré
- 19 104 bd Raymond Poincaré
- 20 92380, Garches
- 21 France
- 22 Email: thomas.cattagni@uvsq.fr
- 23 Tel: +33 1.47.10.79.00

24 ABSTRACT

- 25 **Purpose:** To examine the cardiorespiratory, muscular and skeletal characteristics of an 83-year-26 old champion female master athlete (called DL in this study) who had set multiple world 27 running records in the 80-to-84-year-old age group. Methods: Measures of maximal oxygen 28 uptake (VO_{2max}), maximal heart rate (HR_{max}), maximal isometric torque for knee extensor 29 muscles, thigh and triceps surae muscle volumes, and bone mineral density (BMD) of the 30 proximal femur region were evaluated. Based on previously published equations, physiological 31 age was determined for VO_{2max}, HR_{max} and maximal isometric torque. Muscle volumes for the 32 dominant leg were compared with previously published sex- and age-matched data using Z-33 scores. For BMD, T-score and Z-score were calculated. Results: DL had the highest VO_{2max} (42.3 ml·min⁻¹·kg⁻¹) ever observed for a female over 80 years of age, which gave her a 34 35 remarkable physiological age (27 years). In contrast, she had a physiological age closer to her 36 biological age for maximal isometric torque (90 years) and HR_{max} (74 years). The Z-scores for 37 thigh (0.4) and triceps surae (1.1) muscle volumes revealed that DL's leg muscles were affected 38 almost as much as her sex- and age-matched peers. The T-score (-1.7) for BMD showed that 39 DL had osteopenia but no osteoporosis, and the Z-score (0.7) showed that DL's BMD was 40 similar to that of females of the same age. **Conclusions:** This single case study shows that the 41 remarkable cardiorespiratory fitness coupled with intensive endurance training observed in a 42 female master athlete was not associated with specific preservation of her muscular and skeletal
- 43 characteristics.
- 44

45 KEYWORDS

46 Cardiorespiratory fitness; Neuromuscular function; Maximal oxygen uptake; Bone mineral47 density; MRI.

48

49 **INTRODUCTION**

50 Master athletes, being free from the negative influence of physical inactivity, are considered as

51 models for primary biological aging.¹ Study of the physiological characteristics of high-52 performance master athletes is essential to improve knowledge about the limits of human 53 physiology with age

- 53 physiology with age.
- 54 With performance in athletic endurance events being mainly related to aerobic capacity, master 55 athletes generally present with well-preserved aerobic capacity, as revealed by their high levels 56 of maximal oxygen uptake (VO_{2max}). VO_{2max} values of approximately 40-45 ml·kg⁻¹·min⁻¹
- 50 of maximal oxygen uptake (\sqrt{O}_{2max}). \sqrt{O}_{2max} values of approximately 40-43 mixing -imm 57 (comparable with that observed in sedentary young healthy males) have been reported in 65-
- to-80-year-old champion male athletes,^{2,3} while only ~20-to-25 ml·kg⁻¹·min⁻¹ is generally
- 59 observed in age-matched untrained people.⁴ Two studies even reported a VO_{2max} of 50 ml·kg⁻
- $1 \cdot \text{min}^{-1}$ for an 80-year-old male,⁵ and a master runner with multiple world records.⁶ Female
- 61 master athletes aged between 60 and 70 years presented a VO_{2max} of approximately 38 ml·kg⁻ 62 1 ·min⁻¹.⁷ Like males, their VO_{2max} is comparable to their younger sedentary counterparts
- VO_{2max} is comparable to their younger sedentary counterparts (VO_{2max} : ~30-35 ml·kg⁻¹·min⁻¹]⁴ and considerably higher than their less physically active age-
- 64 matched peers $[VO_{2max}: ~16-21 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}]$.⁴ To date, the VO_{2max} of female master athletes 65 aged over 70-80 years is poorly documented and the VO_{2max} of the most elite remains to be
- 66 investigated to estimate the maximum limit of aerobic capacity in older females.
- 67 While aerobic capacity is known to be related to cardiovascular health, it is also related to
- skeletal muscle health.⁸ However, a recent meta-analysis revealed that age-related declines in
- 69 muscular strength were not prevented in male master athletes competing in endurance events.⁹
- 70 In addition, while males and females may undergo somewhat divergent deterioration of skeletal
- 71 muscle function with advancing age, perhaps due to reductions in sex-specific hormones, most 72 conclusions regarding the skeletal muscle function of master athletes have been based on data
- conclusions regarding the skeletal muscle function of master athletes have been based on data

- collected in males only.^{9,10} The skeletal muscle characteristics of older female master athletes
- thus remain to be investigated.
- 75 While the benefits of chronic endurance exercise have been observed in cardiovascular and 76 muscle function, the benefit for skeletal function is not clear. Wiswell et al.¹¹ showed that
- bone mineral density can be maintained by running in older active males. In contrast, no
- specific protection of bone mineral density (BMD) was observed in post-menopausal female
- 79 master runners.¹² However, it is not known whether this lack of bone protection is also observed
- 80 in female master runners with very high fitness levels.
- This case study aimed to present and compare some physiological characteristics of a champion
 female master runner (called DL in this study) with those of females of the same age.
- 83

84 MATERIALS AND METHOD

85 Subject

- At the time of the evaluation (June 2017), DL was 83 years old. She was a French Caucasian retired beautician, living in Burgundy, France. Her anthropometric characteristics are displayed in Table 1. DL had broken three world records (3,000, 5,000 and 10,000 m running) in the 80-
- to-84-year-old age-group category, by the age of 80. For example, her record in 10,000 m
- 90 outdoor running was 0:55:26. She was still taking part in both walking and running
- 91 competitions at the time of evaluation. DL volunteered and was informed about the nature and
- 92 aims of the study, as well as the associated risks and discomfort prior to giving her written
- 93 consent to participate in the investigation. The protocol was in conformity with the Declaration
- 94 of Helsinki (last modified in 2013).
- 95

96 Typical training and competition schedule (S.1), sport history (S.2), medical history (S.3), and
97 athletics performances/records (Supplemental Table 1) of DL are available as an online
98 supplement.

99

100 Experimental procedure, measurements & data analysis

- 101 The following assessments are displayed in the order in which the tests were performed.
- 102

103 *Maximal voluntary contraction torque of the knee extensor muscles*

- Torque measurements on the right (dominant) leg were performed on an isokinetic 104 105 dynamometer (System pro 4, Biodex Medical System, New York). The subject was seated on 106 the dynamometer chair with a 90° hip angle. The knee joint axis was aligned with the 107 dynamometer axis. The lever arm was attached 2 cm above the medial malleolus with a non-108 compliant strap. The maximal voluntary contraction (MVC) peak torque of the knee extensors 109 was measured during isometric (MVC_{ISO}) and concentric contractions. After a warm-up, DL 110 performed two consecutive 5-s MVC_{ISO}, separated by a 1-min rest period, with the right leg positioned at 70° of flexion (0°=fully extended). After a 1-min rest period, DL successively 111 performed 2 concentric MVCs at $60^{\circ} \cdot s^{-1}$ (MVC₆₀) with a 95° range of motion (from 5° to 100° 112 113 of knee flexion). A 1-min rest period was respected between trials. For each type of contraction
- 114 (e.g. MVC_{iso}), the peak torque of both trials was retained for analysis.
- 115

116 Heart rate and gas exchange during maximal treadmill test

- 117 Because the subject was not familiar with treadmill running, a variable speed/grade procedure
- 118 was used. The test consisted of running at 7 km h^{-1} (0% slope) for 3 min, 8 km h^{-1} (0% slope)
- 119 for 3 min, and 9 km \cdot h⁻¹ (0% slope) for 3 min. After the 9th min, speed was maintained at 9 km/h
- 120 but the slope was increased by 1% every minute until volitional exhaustion. The subject stopped
- 121 the test at the end of the 3% stage after 12 min of effort. Heart rate and respiratory gas exchange
- 122 parameters were recorded continuously during the test and maximal values were determined.

- 123 During the incremental treadmill test, heart rate was recorded every second using a heart rate
- 124 monitor (Polar RS300; Polar Electro Oy, Kempele, Finland), and maximal heart rate (HR_{max})
- was defined as the highest value recorded during the last 30 s of the test. Gas exchange during
- 126 the test was collected using a breath-by-breath portable gas analyzer (Cosmed K4b², Rome, 127 Italy) VO (ml het mint) and maximal asphare diarida are duation (VCO) and het mint
- 127 Italy). VO_{2max} (ml·kg⁻¹·min⁻¹) and maximal carbon dioxide production (VCO_{2max}, ml·kg⁻¹·min⁻¹) 128 ¹) were both defined as the maximal value recorded over a 30-s period during the test. Maximal
- 129 value of respiratory exchange ratio was determined as the highest ratio between the volumes of
- 130 oxygen uptake and carbon dioxide production. Since O₂ pulse during cardiopulmonary exercise
- 131 testing has been associated with the onset of exercise-induced ischemia¹³, and is a powerful
- 132 predictor of mortality in patients with cardiovascular disease,¹⁴ it was also calculated.
- 133
- 134 Lower Limb MRI
- 135 Bilateral magnetic resonance imaging (MRI) scans of both lower limbs were performed using
- 136 a 3.0 Tesla MRI scanner (Siemens Trio, Berlin, Germany) with the participant in supine lying,
- 137 with knees and hips fully extended. Scanning parameters included: repetition time=723 ms;
- 138 echo time=10 ms; α =140°; field of view=400x400 mm; pixel size=0.714 mm; width=560
- 139 pixels; Height=448 pixels; slice thickness=5 mm; slice increment 5 mm; number of slices=162.
- 140 Data were transferred in DICOM format.
- 141 For both legs, the triceps surae, tibialis anterior, quadriceps and other thigh muscles (OTM,
- 142 including knee flexor and adductor muscles, and sartorius) were manually outlined for all the
- slices of the MRI images using 3D image analysis software (Mimics, Materialise, Belgium).
- 144 Examples of muscle area determination are presented in Fig.1A for the thigh muscles, and in
- 145 Fig.1B for the calf muscles. The volume of each muscle or muscle group was calculated from
- 3D reconstruction (selected option on the mimic software: Optimal). A view of the 3Dreconstruction is presented in Fig.1C.
- 147 148

149 Bone mineral density (BMD)

BMD was assessed from dual energy X-ray absorptiometry scan (DXA) (Hologic Bone
Densitometer system n°83752A, model Discovery A, Hologic Company, Marlborough, MA
01752, United States) for the left proximal femur region including the femoral neck,
intertrochanteric region, greater trochanter.

155 Statistical analysis

- 156 While chronological age is determined by date of birth, physiological age can vary according 157 to numerous health metrics. In this study, we chose to compare some physiological 158 characteristics (HR_{max}, VO_{2max}, MVC_{ISO}, and MVC₆₀) of DL by providing her estimated 159 physiological age based on equations previously established in large samples. For HR_{max}, we used the equation (1) of Tanaka et al.¹⁵, obtained from a meta-analysis including 351 studies 160 and 18,712 individuals. For VO_{2max}, we used the equation (2) of Myers et al.¹⁶, obtained from 161 a database including the VO_{2max} (recorded during a maximal treadmill test) of 3,158 healthy 162 females aged 20-79 years. For MVC_{ISO}, we used the equation (3) of Harbo et al.¹⁷, obtained 163 164 from a database including the MVC_{ISO} of 85 females aged 21–75 years. For MVC₆₀, we used the equation (4) of Neder et al.¹⁸, obtained from a database including the MVC_{60} of 51 females 165 166 aged 20-80 years. 167
- $\begin{array}{l} 107\\ 168\\ (1) \ Physiological \ age \ based \ on \ HR_{max} = (208 HR_{max}) / 0.7\\ 169\\ (2) \ Physiological \ age \ based \ on \ VO_{2max} = (VO_{2max} + 0.127 \ x \ weight_{(ibs)} 66.2) / 0.39\\ 170\\ (3) \ Physiological \ age \ based \ on \ MVC_{ISO} = (MVC_{ISO} 216 \ x \ height_{(m)} 0.88 \ x \ weight_{(kg)} + 201) / 0.96\\ 171\\ (4) \ Physiological \ age \ based \ on \ MVC_{60} = (MVC_{60} 1.63 \ x \ weight_{(kg)} height_{(m)} + 41.8) / 1.36\\ 172\end{array}$

For the total thigh, quadriceps and other thigh muscle volumes, data was normalized using Zscores with individual data expressed as the number of standard deviations from the mean of the 'healthy older females' group in the study by Maden-Wilkinson et al.,¹⁹ calculated as:

- 176 177 Z-score = $(\chi - \mu) / \sigma$
- 178

where χ is the value for DL, and μ and σ are the mean and standard deviation respectively, of the older female sample. While reports of triceps surae muscle volume in older females are rare, Z-scores were obtained from the study by Csapo et al.,²⁰ which measured triceps surae volume in five healthy Japanese females aged ~83 years.

To determine whether DL had a risk of bone fracture despite her high physical activity level, 183 184 T-scores of BMD were used to compare DL with healthy young females with peak bone mass 185 according to the manufacturer's instructions and the World Health Organization.²¹ A T-score 186 between +1 and -1 denotes normal bone density. A T-score between -1 and -2.5 indicates low 187 bone density or osteopenia. A T-score of -2.5 or lower reveals the presence of osteoporosis. Z-188 scores for BMD, providing a comparison with the bone density of people of the same age and 189 sex as the patient, were also obtained. A negative Z-score of -2.5 or less should raise concern 190 about a secondary cause of osteoporosis.

191



192 193

Figure 1: Muscle segmentation of right (dominant) leg and volume reconstruction of
 muscles and bones of both legs of the subject.

196 A presents a magnetic resonance image at the mid-point of the femur of the right leg. B presents

a magnetic resonance image in the first third of the tibia of the right leg. C represents the 3D

198 reconstruction of muscle and bone volumes of both legs. Q: quadriceps; OTM: other thigh

199 muscles; TS: triceps surae.

200 **RESULTS**

- As displayed in Table 1, DL had an exceptional VO_{2max} (42.3 ml·kg⁻¹·min⁻¹) and normal muscle strength for her age. Her lower limb muscle volumes were just slightly better than expected for her age (Table 2). The bone mineral density was 0.739 g·cm⁻² (T-score: -0.8; Z-score: 1.5) for the femoral neck, 0.523 g·cm⁻² (T-score: -1.9; Z-score: -0.3) for the greater trochanter, 0.986 g·cm⁻² (T-score: -0.8; Z-score: 1.6) for the intertrochanteric region and 0.745 g·cm⁻² (T-score: -1.7; Z-score: 0.7) for the total of the left proximal femur region.
- 207 208 **DISCUSSION**

This single case study reported, for the first time, some physiological characteristics of a highlevel female master runner aged over 80 years.

- 211 During the maximal treadmill test, DL had a respiratory exchange ratio at VO_{2max} just below 1, indicating a possible underestimation of her true VO_{2max}. Despite this, DL presented, to the best 212 213 of our knowledge, the highest value of VO_{2max} ever observed for an octogenarian female. On 214 the basis of her VO_{2max} , we showed that she had a physiological age of ~27 years. Her VO_{2max} was slightly higher than in young females (~30-35 ml·kg⁻¹·min⁻¹)⁴ and 60-to-69-year-old 215 endurance-trained females (~38.0 ml·kg⁻¹·min⁻¹),⁷ but considerably above the mean values in 216 217 females aged 70-to-79-year-old (~16-21 ml·kg⁻¹·min⁻¹).⁴ While DL had a low body mass compared to the populations of young and elderly females, her absolute $VO2_{max}$ (1.99 l·min⁻¹) 218 219 was twice that of females aged 70-to-79-year-old (VO2_{max}: 1.05 l·min⁻¹) and comparable to that of young females (20-25 years, VO2_{max}: 2.04 1 min⁻¹).⁴ It can be assumed that DL had some 220 hereditary advantages for cardiorespiratory fitness, VO_{2max} and its trainability being related to 221 genetic predisposition.²² However, age-related decline in VO_{2max} could have been prevented, 222 due to her participation in a training program for competitive running performance of distances 223 up to 10km, from the age of 69 years. Indeed, it is well known that older persons can minimize 224 the reduction in age-related $VO2_{max}$, if they maintain high levels of physical activity.²³ In 225 226 addition to her past and actual training program, DL's level of physical training is evidenced 227 by her very low body fat content (~15%) in comparison to reference values in elderly females 228 $(\sim 40\%)$.²⁴ DL's physiological age for HR_{max} (~ 74 years) was slightly lower than her biological age (83 years). The high VO_{2max} and HR_{max} level explained the high value of O₂ pulse, 229 230 corresponding to the mean values reported in a population in the 5th decade.²⁵ It is worth noting 231 that O₂ pulse increased almost linearly during the treadmill test, indicating an absence of cardiac 232 ischemia.¹³ These observations attest the extremely well-preserved cardiovascular and 233 respiratory fitness of this master female athlete.
- 234

235 As shown by the T-scores and Z-scores for BMD, DL did not suffer from sarcopenia. However, 236 her muscle characteristics seemed to be similar or only slightly better than those generally 237 observed for her age and sex. DL's physiological age based on isokinetic strength (83 years) 238 was fairly similar to her biological age (83 years), but it was higher when based on her maximal 239 isometric strength (90 years). It is worth noting that the equation used to calculate DL's 240 physiological age only included females aged from 21 to 75 years, which may have led to an 241 overestimation of her physiological age. Indeed, an accelerated decline in physical performance 242 has been observed after approximately 80 years, suggesting that physiological functions decline 243 rapidly at around 80 years.²⁶ The study of DL's leg muscle volumes confirmed a potential overestimation of her physiological age. Her thigh muscle volumes were fairly comparable with 244 those of older females aged ~72 years,¹⁹ showing that DL's muscle quantity was well-preserved 245 for her age. This preservation was more noticeable for the triceps surae, as it was 22% greater 246 than that of five Japanese females in the same age range.²⁰ Our observations regarding DL's 247 muscle function are in line with a recent meta-analysis⁹ in male master athletes competing in 248 249 endurance events, which showed that, in contrast to master strength/power athletes, chronic

- 250 endurance exercises did not prevent the loss of muscular strength. Chronic endurance training
- therefore does not seem to prevent the age-related decline in muscular strength for either males
- 252 or females.
- 253

DL's BMD for the proximal femur region was within the osteopenia range, only revealing an increased fracture risk. Therefore, DL did not have osteoporosis, despite the early menopause and relatively low calcium intake, probably due to the regular training conducted over the minimum effective amount shown to positively affect BMD [2.5 exercise sessions/week].²⁷ However, the Z-scores at the proximal femur region (0.7) showed that DL's BMD was clearly similar to that of females of the same age. This result confirms that post-menopausal female

260 master runners do not seem to benefit from specific bone protection.¹²
261

262 CONCLUSION

The present single case study of a master female runner shows that remarkable cardiorespiratory fitness, associated with long-term endurance training, is not associated with a specific preservation of muscle and skeletal characteristics.

267 PRACTICAL APPLICATIONS

The results of this study do not support the use of highly intensive aerobic training to prevent age-related declines in muscle strength and bone quality in females.

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271 CONFLICTS OF INTEREST

- 272 All authors declare no conflicts of interest.
- 273

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