Case Report

How to Be 80 Year Old and Have a VO$_2$max of a 35 Year Old

Trine Karlsen, 1,2 Ingeborg Megård Leinan, 1,2
Fredrik Hjulstad Bækkerud, 1 Kari Margrethe Lundgren, 1 Atefe Tari, 1
Sigurd Loe Steinshamn, 1,3 Asbjørn Støylen, 1,4 and Øivind Rognmo 1,2

1 K.G. Jebsen Center of Exercise in Medicine, Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, 7491 Trondheim, Norway
2 St. Olav’s University Hospital, Trondheim, Norway
3 Department of Pulmonary Medicine, St. Olav’s University Hospital, Trondheim, Norway
4 Department of Cardiology, St. Olav’s University Hospital, Trondheim, Norway

Correspondence should be addressed to Trine Karlsen; trine.karlsen@ntnu.no

Received 6 November 2014; Accepted 2 February 2015

Academic Editor: Masahiro Kohzuki

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Background. To discuss the cardiovascular and pulmonary physiology and common risk factors of an 80-year-old man with a world record maximal oxygen uptake of 50 mL kg$^{-1}$ min$^{-1}$. Methods. Case report. Results. His maximal oxygen uptake of 3.31 L min$^{-1}$, maximal heart rate of 175 beats min$^{-1}$, and maximal oxygen pulse of 19 mL beats$^{-1}$ are high. He is lean (66.6 kg) and muscular (49% skeletal muscle mass). His echo parameters of mitral flow (left ventricular filling, $E = 82$ cm s$^{-1}$ and $E/A = 1.2$) were normal for 40- to 60-year-old men. Systolic and diastolic function increased adequately during exercise, with no increase in left ventricular filling pressure. He has excellent pulmonary function (FVC = 4.31 L, FEV1 = 3.41, FEV1/FVC = 0.79, and DLCO = 12.0 S1 L$^{-1}$) and normal FMD and blood volumes (5.8 L). He has a high level of daily activity (10,900 steps day$^{-1}$ and 2.51 hours day$^{-1}$ of physical activity) and a lifelong history of physical activity. Conclusion. The man is in excellent cardiopulmonary fitness and is highly physically active. His cardiac and pulmonary functions are above expectations for his age, and his VO$_2$max is comparable to that of an inactive 25-year-old and of a normal, active 35-year-old Norwegian man.

1. Introduction

A recent study reported world-record maximal oxygen uptake (VO$_2$max) for octogenarian endurance athletes of between 34 and 42 mL kg$^{-1}$ min$^{-1}$, with reference values for inactive subjects being 21 mL kg$^{-1}$ min$^{-1}$ [1]. It is well known that VO$_2$max reduces with aging [2, 3], and several factors, including systolic and diastolic heart function, pulmonary function and diffusion capacity, peripheral circulation, and skeletal muscle metabolism and mass, may limit VO$_2$max [4–6]. Maintaining a high VO$_2$max may be essential for healthy aging, because VO$_2$max is a strong and independent predictor of mortality [7] and protects against cardiovascular mortality and morbidity [8]. Therefore, understanding how to maintain it is vital. The purposes of this publication are to describe the physiology of an 80-year-old man with an extraordinarily high VO$_2$max of 50 mL kg$^{-1}$ min$^{-1}$ and to discuss how it is possible to have “VO$_2$max of a 35-year-old” at 80 years of age. The man’s impressively high VO$_2$max, combined with a lifelong history of physical activity, is unique and could be a world record at his age.

2. Methods

The case was investigated in February and March 2013. First, resting blood pressure and heart rate (Phillips IntelliVue MP50, Germany) and body composition by bioimpedance (InBody 720, Biospace Co., Ltd., Seoul, Korea) were measured, followed by a VO$_2$max treadmill-running test (breath-by-breath measurement with the MMX-II, CORTEX Biophysik GmbH, Germany). The test-retest reliability for the equipment used in this study has previously been reported to have a test-retest correlation for oxygen uptake of 0.99, $p < 0.001$, with a coefficient of variation of 1.8% [9]. After
a 15-minute warm-up, the VO$_2$ max was tested with treadmill running on a fixed inclination of 10% and an increase in speed approximately every minute until exhaustion. VO$_2$ max was defined as the mean of the highest three consecutive 10-second measurements where the VO$_2$ leveled off despite an increase in speed. The results of the VO$_2$ max test were reconfirmed twice in two test laboratories (once in our laboratory and once in a local Olympic training facility laboratory).

Second, after 12 hours of fasting, flow-mediated dilatation (FMD) in the brachial artery was measured with a vascular ultrasound (Vivid 7, GE Vingmed, Norway) [10]; blood samples were collected and analyzed at the St. Olav’s hospital's biochemical laboratory, and the total blood, plasma, erythrocyte volume, and hemoglobin mass were measured with the optimized carbon monoxide rebreathing method, where carbon monoxide serves as a marker of hemoglobin (Bayreuth, Germany) [11]. Furthermore, flow-volume spirometry and diffusion capacity were measured with standard procedures (SensorMedics Vmax Encore 22, Homestead, FL, USA), and resting and exercise cycling cardiac echocardiography were performed with an increasing protocol until the heart rate reached ~100 beats min$^{-1}$ (Vivid 7, GE Vingmed, Norway) with simultaneous electrocardiogram ECG recordings (Siemens Medical, Germany). In addition, the man wore a physical activity sensor for 6 days (Armband, Senseware, USA).

The man volunteered to be investigated and have the results published as a case report. The Central Norway Regional Ethical Committee was consulted for ethical advice; however, no application was needed, because the study did not fall under the Norwegian law for medical research. The authors were advised to write an informed consent to the man, explaining in detail the physiological examinations and the publication plan. The authors complied, and the consent form was signed by the man before the physical examinations.

### 3. Results

The man is lean and muscular with a strong upright posture while standing (Figure I(a)). He has never smoked and is currently medicated with aspirin. No definite indication for aspirin could be found according to established guidelines; the reason for the treatment may be due to the pacemaker, combined with the subjects’ age, being taken as an indication of general cardiovascular disease. His blood biomarkers are normal, including normal renal function, and his other demographic variables are displayed in Table 1.

His VO$_2$ max is 50 mL·kg$^{-1}$·min$^{-1}$, corresponding to 3.31 L·min$^{-1}$ and 14 METs (14 standard metabolic equivalents) (Figure I(b)). At maximal effort, his ventilation (VE) was 111 L·min$^{-1}$, and his breathing frequency was 41 L·min$^{-1}$. His maximal heart rate was 175 beats·min$^{-1}$, and his oxygen pulse (O$_2$-pulse) was 19 mL·beats$^{-1}$. His anaerobic threshold was at 86% of VO$_2$ max (VO$_2$ = 42.8 mL·kg$^{-1}$·min$^{-1}$). The VE/VCO$_2$ slope was 29.7. His maximal running speed was 10 km·hr$^{-1}$ at 10% treadmill inclination, and his maximal RER was 1.14, indicating a high effort during the test.

He received a pacemaker ~10 years ago and is in a pacemaker rhythm at rest. His lowest resting heart rate was 52 beat·min$^{-1}$ during sleep and 60 beats·min$^{-1}$ at daytime. The pacemaker was inserted due to intermittent second-degree AV-block, at the time diagnosed as Mobitz type 2. His cardiac function is described in Table 2, which shows abnormal cardiac motion patterns at rest due to the pacemaker rhythm. During a light-intensity, upright bicycle test, he immediately went into sinus rhythm when he started to pedal, and his heart's motion patterns normalized. Even in pacemaker rhythm, his echo parameters of mitral flow (left ventricular filling) were normal for 40- to 70-year-old men in the HUNT study [12]. There were adequate increases in both systolic and diastolic function during exercise, with no increase in left ventricular filling pressure. Findings were in accordance with a highly trained group of 74-year-old men who were previously studied [4]. His baseline brachial artery diameter was 4.41 mm, and his FMD was 2.72%.

His pulmonary function was above average for his age. His forced ventilator capacity (FVC) was 4.31 L, his forced expiratory volume in one second (FEV1) was 3.41 L, and his FEV1/FVC ratio was 0.79. His lung diffusion capacity was high, with a DLCO of 12.0 S I. Maximal voluntary ventilation (MVV) was calculated using FEV1 × 40 [13]. Estimated MVV was 136 L·min$^{-1}$, and the ratio between VE at maximal exercise and the calculated MVV was 0.82. His breathing reserve was 25 L·min$^{-1}$.

His total blood, plasma, and erythrocyte volumes were 5.8, 3.6, and 2.2 L, respectively, and his total Hb-mass was 744 g, with hemoglobin and hematocrit values of 14.1 g·dl$^{-1}$ and 43%. When expressed per kilogram of body mass, his blood, plasma, and erythrocyte volumes were 87, 54, and 33 mL·kg$^{-1}$, respectively, and his total Hb-mass was 11.2 g·kg$^{-1}$.

He has a lifelong history of endurance and strength-exercise training. Born and raised on a small farm in a roadless mountain region, his childhood was dominated by the vigorous manual labor of farm work, fishing, hunting, and berry harvesting (Figures I(c) and I(d)), as well as exercise training. He has continued this lifestyle as an adult. He currently self-reports ~30 minutes of structured endurance and strength training 3 times/week (Figure I(e)), ~20 minutes of endurance training, including short durations with moderate-to-lactate threshold intensity, and ~10 minutes of strength training three times per week, mainly on the upper body and core with 10–12 repetitions per set. Each year, he takes a 7-day ski trip in the mountains and has competed in ultraendurance ski races. His current objectively measured daily activity level is high at 10,843 steps·day$^{-1}$. His total energy expenditure (TEE) was 2,476 Kcal·day$^{-1}$, out of which 877 Kcal·day$^{-1}$ was due to active energy expenditure (AEE). Daily active time (≥3 METs) was 2:51 hr·day$^{-1}$, with 2:31 hr·day$^{-1}$ of moderate activity (3–6 METs) and 0.21 hr·day$^{-1}$ of vigorous activity (≥9 METs), while no time of >9 METs was logged. We are unable to confirm any sports competition results from his early or middle age, but online
result services from the two major ultraendurance cross-country ski competitions in Scandinavia, the Birkebeiner (54 km) and the Vasaloppet (90 km) ski races, show his participation and completion in three races. In 2007, he completed the Vasaloppet race and, in 2002 and 2004, he completed the Birkebeiner race with finishing times of 4:41:25 and 4:46:04 hours, respectively, coming in as number 130 (65–69-year age group) and number 21 (70–74-year age group) in his respective competition groups. In 2004, he also competed in the Birkebeiner mountain bike race (89 km) and the Birkebeiner mountain half marathon (21 km). His finishing times were 4:51:52 and 02:01:45 hours, making him number 5 and number 6 in his age class (70–74-year age group).

4. Discussion

The man has a high VO$_2$$_{max}$ for his age, ~50% above the mean for 80-year-old men in Norway [2] and above the 90 percentile (44.2 mL·kg$^{-1}$·min$^{-1}$) in the ACSM guidelines [14]. His VO$_2$$_{max}$ is higher than the mean of 30- to 39-year-old Norwegian men and inactive 20- to 29-year-old Norwegian men [2], and it is also 8 mL·kg$^{-1}$·min$^{-1}$ above the highest VO$_2$$_{max}$ reported among 12 Swedish lifelong octogenarian endurance athletes, including a former Olympic champion [1]. His MET value of 14 is high, which places him in the low mortality risk category ≥10 METs [8, 15] as well as above the 44.2 mL·kg$^{-1}$·min$^{-1}$ threshold where an unfavorable cardiovascular risk profile is apparent in Norwegian men [2]. This is supported by his measured risk parameters. The man reports having been tested twice (at 25 and 45 years of age) with cardiopulmonary exercise as part of his work health services, which resulted in a VO$_2$$_{max}$ of ~75 and ~58 mL·kg$^{-1}$·min$^{-1}$. This represents a relative 7% reduction in VO$_2$$_{max}$ per decade, which is comparable to the 6–11% reduction per decade reported elsewhere in both well-trained and sedentary men [1, 3, 16–19]. His estimated absolute reduction in VO$_2$$_{max}$ of 0.45 mL·kg$^{-1}$·min$^{-1}$ per year from 25 to 80 years of age is highly comparable to values reported for active subjects in the meta-analysis by Wilson and Tanaka (4.6 mL·kg$^{-1}$·min$^{-1}$ per
compared to the values from the Norwegian HUNT study was normal (tissue Doppler) to super normal (mitral flow),

Despite being in pacemaker rhythm, his diastolic function and left ventricular volume, with normal function parameters.

19% higher than those in the published data on older men

His total blood, plasma, and erythrocyte volumes were, respectively, 9% and 15% above men his age in Norway [9] and lifelong Swedish athletes [1], indicating a high maximal stroke volume. He has a high maximal heart rate for his age, 12 beats·min⁻¹ higher than the mean of Norwegian men his age [9, 20]. Together with a high O₂ pulse, this indicates a large cardiac output during exercise. His total blood, plasma, and erythrocyte volumes were ~17–19% higher than those in the published data on older men

moreover, these volumes were at the levels of normal-to-moderate performance endurance athletes [22] and yet below the values of elite athletes [23]. He clearly has an “athlete’s” heart with bradycardia; however, no information on this exists from earlier in his life.

His vascular function was normal for his age and gender, with an FMD of 2.7%. His FMD is 3% below the mean of a Norwegian reference population, but he has a large baseline diameter and no indication of endothelial dysfunction, because his FMD is above 0% [24]. His blood biomarkers were also normal and low for his age as was his blood pressure, with no indication of elevated cardiovascular risk markers.

His lung function was above average for his age. His FVC, FEV₁, and FEV₁% were at 128%, 126%, and 97% of the age-predicted values, respectively. His diffusion capacity for carbon monoxide was normal (147 cm³·min⁻¹·kPa⁻¹) [12]. Without any pose of venous gas trapping, this indicates a normal ventilation-perfusion ratio with a normal maximum ventilation of 111 L. His breathing reserve is normal at 25·L·min⁻¹ and 82% of predicted MVV, which is comparable to an age reference value of 26.6·L·min⁻¹ [16]. Without his supranormal dynamic lung volumes, he probably would have been ventilatory-limited as a “normal for age” FEV₁ of approximately 2.70 L, giving a calculated MVV of 108 L, which is below his maximal VE of 111 L. His VE/VCO₂ slope is normal, despite his high age, indicating a good match of ventilation and perfusion in the pulmonary ventilation, and he has a maximal VE/VO₂

Table 1: Demographic variables.

| Variable                | Value   |
|-------------------------|---------|
| Body weight (kg)        | 66.6    |
| BMI                     | 23      |
| Fat mass (%)            | 12      |
| Skeletal muscle mass (%)| 49      |
| Waist-to-hip ratio      | 0.85    |
| Systolic blood pressure (mmHg) | 136 | Diastolic blood pressure (mmHg) | 78 |
| Total cholesterol (mmol·L⁻¹) | 4.00 |
| HDL cholesterol (mmol·L⁻¹) | 1.76 |
| LDL cholesterol (mmol·L⁻¹) | 1.99 |
| Triglyceride (mmol·L⁻¹)  | 0.55    |
| TSH (mL·L⁻¹)            | 1.75    |
| Blood glucose (mmol·L⁻¹) | 5.2     |
| B-HbA1c (%)             | 6.2     |
| C-peptide (nmol·L⁻¹)    | 0.3     |
| Creatinin (µmol·L⁻¹)    | 82      |
| Estimated GRF (mL·min⁻¹) | 78    |

Demographic description of the case. BMI: body mass index, GRF: glomerular filtration rate, HDL: high density lipoproteins, LDL: low density lipoproteins, TSH: thyroid stimulating hormone.

Table 2: Cardiac findings at rest and light exercise with echocardiography.

| Parameter                                      | Rest          | Light exercise |
|-----------------------------------------------|---------------|----------------|
| Heart rate                                    | 60            | 100            |
| Rhythm                                        | Pacemaker     | Sinus          |
| End diastolic volume (mL)                     | 147           | 124            |
| Ejection fraction (%)                         | 54            | 80             |
| Mitral annulus displacement (cm)              | 1.2           | 1.2            |
| Mitral flow E (cm·s⁻¹)                        | 82*           | 112            |
| Mitral flow E/A                               | 1.2*          | 12.0           |
| E Deceleration time (ms)                      | 199*          | 7.5*           |
| Isovolumic relaxation time (ms)               | 94*           | 10.9*          |
| Tissue Doppler systolic velocity (S'—cm·s⁻¹) | 8.0*          | Tissue Doppler early diastolic velocity (e'—cm·s⁻¹) |
| E/e'                                          | 10.9*         | 10.0           |

Echocardiographic findings at rest and during light, upright bicycle exercise. The * denotes normal values for males in the age interval of 40–60 years in the HUNT study, while § denotes values that are normal for males in the age range of >60 [12].
of 33.5, indicating a normal ventilatory cost for his oxygen uptake [25].

Despite self-reporting a low volume of systematic exercise training (90 min per week), he is highly physically active, engaging in 83% more physical activity than the minimum daily recommendation [26]. He walks ~4,100 steps-day$^{-1}$ more than the mean of Norwegian men above 65 years old and ~2,650 steps-day$^{-1}$ more than Norwegian men between 20 and 64 years [27]. He outwalks the octogenarian lifelong Swedish athletes by ~2,800 steps-day$^{-1}$ and untrained men by ~6,500 steps-day$^{-1}$. He is moderately and vigorously active, 1050 min-wk$^{-1}$ and 147 min-wk$^{-1}$, which is seven times and two times above the recommendations for moderate and high-intensity physical activity of ≥150 min-wk$^{-1}$ and ≥75 min-wk$^{-1}$, respectively [26]. His habits may indicate that large volumes of both moderate and vigorous physical activity are needed to maintain a high VO$_{2\text{max}}$ at this age, in contradiction to what has been reported by others [18].

The man describes the week he wore the activity sensor as a normal week for him in terms of physical activity. As the sports competition results we have are limited to cross-country ski races when the man was 69, 71, and 74 years of age, we are unable to discuss the change in performance from young age.

There was a slight increase in his competition time from 2002 to 2004 of 4.39 minutes; however, as the weather, snow, and ski conditions are vital for performance in ski races, we are unable to pinpoint the reason for the ~2% increase in race time. In 2004, he was number 21 in his age group (70–74 years) in the race, while he was number 130 in his age group in 2002 (65–69). Compared to the winning times in his age classes, his race time was a respective 27% and 10% slower than the winner in his age group in 2002 (65–69 years) and 2004 (70–74 years), and this is most likely due to him being on the younger end in his competition group in 2004, while he was oldest within his group in 2002.

In addition to endurance exercise training, he reports performing systematic strength training. His maximal or functional muscle strength was not measured in this study; however, his large muscle mass and ability to perform repeatedly high-demand strength exercises (Figure 1(e)) suggest that a strong and functional skeletal muscle mass may positively affect his high cardiopulmonary fitness.

5. Conclusion

The 80-year-old man has excellent “35-year-old” cardiopulmonary fitness with a low cardiovascular risk profile and might have a world-record VO$_{2\text{max}}$ for his age and gender due to excellent cardiac function (both systolic and diastolic), pulmonary function, and a good match between the cardiac and pulmonary system. In addition, a large, strong skeletal muscle mass; age-elevated blood volume and hemoglobin mass; and normal arterial vascular endothelial function may contribute positively. He is highly physically active and has a lifelong history of physical activity and exercise training. His highly physically active lifestyle may be his “fountain of youth” at 80 years of age, together with a high level of VO$_{2\text{max}}$ at young age.

Perspectives

It is possible to be an 80-year-old man and have a VO$_{2\text{max}}$ of a 35-year-old with a low cardiovascular risk profile. The volume of physical activity for an active and highly fit 80-year-old man is high, seven and two times higher than recommendations for moderate and vigorous physical activity. The reduction in VO$_{2\text{max}}$ with aging is normal in the 80-year-old man, indicating the importance of having a high maximal oxygen uptake at a young age.

Conflict of Interests

The authors have no conflict of interests to declare.

Acknowledgments

The authors are grateful for the technical assistance of research nurse Solfrid Meyer Lowensprung during pulmonary function testing, to our case subject, and for pictures courtesy of Julius Margido Jensen. They are also grateful for the picture courtesy of Kåre Grip (Figure 1(c)). Research grants from the Central Norway health authorities, the K.G. Jebsen Center for Exercise in Medicine, and the Norwegian University of Science and Technology covered the salaries of the scientists.

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