

## Physiological and anthropometric profile of Colombian cross-country mountain bikers across age categories (U15, U17, and U20)

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Published online: March 31, 2026

Accepted for publication: March 15, 2026

DOI:10.7752/jpes.2026.03048

### Abstract:

**Background/Objectives:** In recent years, cross-country mountain biking (Mtb-Xco) has attracted considerable research attention, with studies investigating factors that influence performance at physiological, mechanical, anthropometric, and technical levels. Despite the growing scientific output regarding predictors of performance in Mtb-Xco from physiological and anthropometric perspectives, few studies integrate a joint analysis of variables based on categories, particularly in the Colombian and Latin American populations. **Materials and methods:** A cross-sectional study was performed to identify key physiological and anthropometric variables in young Colombian mountain bikers. A convenience sample of 21 athletes was organized into three age categories: U15–16 (n = 8), U17–19 (n = 7), and U20 (n = 6). Descriptive statistics, including mean and standard deviation (SD), were calculated, and the normality and homoscedasticity of the data were verified using the Shapiro–Wilk test. Parametric tests were subjected to ANOVA, with an effect measure  $\eta^2$  for the means and standard deviation; non-parametric tests were developed using the Kruskal-Wallis test with medians and parameter  $\epsilon$ . **Results:** Vo2max and maximum power in the maximum values of the incremental test with moderate-large effect sizes ( $\eta^2$  or  $\epsilon^2$ ) were the most decisive factors in the incremental test, as was Vo2HR, which reported differences between categories in both VT1, VT2, and Vo2max. Regarding the components of the anthropometry variable, significant differences were found in the circumference of the relaxed arm ( $p < 0.02$ ), flexed arm ( $p < 0.04$ ), and calf circumference ( $p < 0.03$ ). **Conclusions:** Taken together, these findings indicate that performance development in young Mtb-Xco mountain bikers depends to a greater extent on physiological adaptations and specific morphological changes than on body composition estimates, providing key information for the formative stages and planning of sports training.

**Key Words:** body composition; Endurance performance; Ventilatory thresholds; Cardiopulmonary exercise; Mountain bike

### Introduction

Olympic cross-country mountain biking (Mtb-Xco) is characterized as an intermittent endurance sport with high energy and physiological demands (Prinz et al., 2021). It is practiced on cross-country circuits that combine natural trails, technical descents, steep climbs, and flat sections, where athletes must navigate and overcome artificial obstacles such as droops, banked turns, rock gardens, and jumps, which increase the technical level of the competition (Arriel et al., 2022). Official Mtb-Xco tracks comprise courses of between 3.5 and 6 km per lap, with a total duration of approximately 70 to 120 minutes, as established in the UCI regulations (Version 01/01/2025). Likewise, the number of laps (5 to 9) is established by category (junior, under-23, or elite) and may be modified depending on terrain conditions or climatic factors (Union Cycliste Internationale, 2025).

In recent years, Mtb-Xco has been the subject of considerable research interest, driving studies aimed at identifying the most decisive factors influencing performance at the physiological, mechanical, anthropometric, and technical levels (Novak et al., 2018; Bejder et al., 2019). Multiple studies have evaluated and analyzed physiological demands in controlled environments (laboratories) through simulated tests, incremental tests (Impellizzeri & Marcora, 2007; Smekal et al., 2015), and tests such as the sprint interval exercise test (SIXT) (Schneeweiss et al., 2019; Hays et al., 2021; Hebisz et al., 2022). Likewise, technological advances have made it possible to monitor different metrics such as Power (Po), Cadence (Cad), Heart Rate (HR), and Speed (Vel) in real competition and training using devices and sensors (Baron, 2001; Macdermid & Stannard, 2012; Granier et al., 2018; Hays et al., 2018; Prinz et al., 2021; Bouillod et al., 2022; Becerra Patiño et al., 2025). However, the analysis of different variables and metrics may be incomplete if there is no correlation between the different

performance indicators obtained in the laboratory and those recorded in competition (Inoe et al., 2012; Hays et al., 2018).

Competition results show that mountain bikers reach an average heart rate equivalent to 90% of their maximum heart rate, which corresponds to approximately 80-85% of their maximum oxygen consumption ( $\text{VO}_{2\text{max}}$ ) (Impellizzeri & Marcora, 2007; Bejder). Likewise, it has been observed that the recorded power remains close to 70% of the time below the maximum aerobic power (MAP) and approximately 30% of the time above it (Prinz et al., 2021). On the other hand, at the start of the race, the athlete must find an ideal position to increase their chances of winning; consequently, the power recorded in this phase is high, showing the highest peak power (Ppeak) reached during the competition (Macdermid & Morton, 2012; Hays et al., 2018; Novak et al., 2018).

Additionally, during competition, variations in power above the anaerobic threshold occur, distributed over short periods of time (5 to 300 s), indicating a high demand for force at high speed or, alternatively, the effect of low speed with a significant manifestation of force (Stapelfeldt et al., 2004; Macdermid & Stannard, 2012). These characteristics confirm the mixed nature of the efforts employed in Mtb-Xco, in which there is a greater prevalence of the sustained aerobic system combined with intermittent episodes of high intensity, requiring complex interaction between the systems (Inoue et al., 2012; Hays et al., 2018).

On the other hand,  $\text{VO}_{2\text{max}}$  is considered one of the most analyzed variables in Mtb-Xco. Different studies show that male mountain bikers in the U23-elite category reach values between 74-78 ml/min/kg, while female mountain bikers reach 65-67 ml/min/kg (Prinz et al., 2021; Arriel et al., 2022), while juniors reach approximately 72 ml/min/kg for men and 63 ml/min/kg for women (Fornasiero et al., 2018; Hebisz et al., 2018; Mirizio et al., 2021). Likewise, MAP is a useful parameter for determining different training zones, planning workouts (Schneeweiss et al., 2022), and managing pacing in competition (Viana et al., 2018; Hays et al., 2018). Both MAP and  $\text{VO}_{2\text{max}}$  are variables that are strongly related to performance in Mtb-Xco. Similarly, when correlating these parameters based on the composition and body measurements of mountain bikers, the anthropometric profile becomes more relevant for athletes and coaches to take into account (Arriel et al., 2022).

Findings have shown that anthropometric profile is a determining factor for athletic performance (Fornasiero et al., 2018), particularly body mass and body fat (Arriel et al., 2020). This relationship is explained by the direct association derived from the weight-to-power ratio, which determines the ability to generate power relative to weight, important for performance especially in climbs (Lee et al., 2002; Schomöller et al., 2021). On the other hand, it has been shown that mountain bikers have a similar profile to road climbers and closely match the ectomorphic somatotype (Lee et al., 2002; Fornasiero et al., 2018). It has also been suggested that anthropometric measurements should follow guidelines such as those proposed by the International Society for the Advancement of Kinanthropometry (ISAK) (Sánchez-Muñoz et al., 2018). However, there are measurements such as height or wingspan that do not influence athletic performance in Mtb-Xco, but they should be taken into account to monitor the growth and development of athletes (Sánchez-Muñoz et al., 2018; Fornasiero et al., 2018; Mirizio et al., 2021).

Despite the growing scientific output regarding predictors of performance in Mtb-Xco from physiological and anthropometric perspectives, few studies integrate a joint analysis of variables based on categories, particularly in the Colombian and Latin American populations. Such studies could provide valuable information for analyzing the physiological and anthropometric variables that determine performance in Colombian cycling (Cano-Giraldo et al., 2025). Therefore, it is essential to understand the differences and relationships between variables by category in order to establish performance profiles, optimize talent selection processes, and design age-appropriate training strategies. In this regard, the objective of this study is to characterize and compare the physiological and anthropometric variables of mountain bikers in the U-15, U-17, and U-20 categories competing in Olympic cross-country (XCO).

## Materials and Methods

### *Design and Procedures*

Cross-sectional study (O'Donoghue 2010) developed to characterize cardiorespiratory fitness and anthropometric profile in competitive mountain bikers belonging to the local team. Data were collected prospectively at a single time point for each participant. Sample selection was based on convenience, due to participant availability and study objectives. The intervention was carried out during the first part of the 2025 season (January-February). This study adheres to the principles of the Declaration of Helsinki (2025) and Resolution 8430 of the Colombian Ministry of Health, which establishes the procedures for non-invasive evaluations in human subjects, declaring the study to be low risk because it does not perform invasive procedures. Each of the athletes was accompanied by their parents and/or legal guardians to sign the informed consent form for voluntary participation in the study.

Groups of three mountain bikers were organized to undergo anthropometric and physical fitness assessments on the same day. Different days were assigned for the intervention over an eight-week period until all 21 participants had been evaluated. After completing the tests, the research team downloaded the data to a laptop and imported it into an Excel spreadsheet to obtain each of the variables.

### Participants

This study was conducted with 21 cyclists. The athletes were selected into three groups according to their age. The main characteristics of the sample evaluated are shown in Table 1. To participate in the study, athletes had to meet the following inclusion criteria: (i) absence of musculoskeletal injuries or health problems in the two months prior to the evaluations, (ii) belonging to the local team and having at least four years of experience practicing the sport, (iii) having undergone ergospirometry and anthropometry, (iv) training at least five times a week and having experience in at least one national cup. Conversely, the exclusion criteria were: (i) having health problems that prevented physical and cognitive effort during the tests, (ii) returning from an injury or undergoing rehabilitation, and (iv) training without competing. All athletes were healthy at the time of the evaluations.

**Table 1.** Main characteristics of the sample.

| Variables           | U15-16 (n:8) | U-17-19<br>(n:7) | ≥ U20<br>(n:6) |
|---------------------|--------------|------------------|----------------|
| Age (years)         | 15,75        | 17,57            | 21,17          |
| Body mass (kg)      | 56,55        | 63,01            | 60,47          |
| Height (cm)         | 167,85       | 169,8            | 166,5          |
| BMI                 | 20,03        | 21,97            | 21,87          |
| Sitting Height (cm) | 84,33        | 91,03            | 89,03          |
| Wingspan (cm)       | 168,38       | 170,11           | 176,58         |

Note: kg: kilograms; cm: centimetres.

### Equipment

For body mass assessment, the OMROM model HBF-514C scale (Kyoto, Japan) was used, with an accuracy of 0.1 cm. Height was measured with a portable stadiometer (Seca, 213) (Hamburg, Germany). The MetaLyzer 3B (CPET/CPX) portable and modular ergospirometry system was used, designed to provide a complete and accurate medical analysis of lung, heart, and metabolic function in athletes. The following variables were evaluated: i) respiratory: tidal volume (VT), minute ventilation (VE), respiratory rate (BF), ventilatory equivalents (VE/VO<sub>2</sub>, VE/VCO<sub>2</sub>); gas exchange: VO<sub>2</sub> (oxygen consumption), VCO<sub>2</sub> (carbon dioxide production), respiratory quotient RER (VCO<sub>2</sub> / VO<sub>2</sub>), inspired and expired fractions of O<sub>2</sub> and CO<sub>2</sub>; metabolism and energy: total energy expenditure (kcal/min), resting metabolic rate (RMR), energy substrates used (fat and carbohydrate oxidation), metabolic/economic efficiency; performance variables: ventilatory threshold 1 (VT1), ventilatory threshold 2 (VT2), maximum oxygen consumption (VO<sub>2</sub>max), and VO<sub>2</sub> kinetics. Heart rate (HR) and heart rate variability (HRV) variables were measured using the Polar H10 chest strap.

The Tacx Flux Smart 2 (Garmin®, Netherlands) was used, which is a direct drive smart trainer designed for evaluating cycling performance under controlled conditions. It has internal power and cadence sensors with an accuracy of ±2–2.5%. It connects via ANT+® and Bluetooth® Smart protocols, which facilitates integration with physiological recording and analysis platforms, allowing data synchronization with heart rate monitors, gas analyzers, and experimental control software.

The anthropometric assessment was performed by a certified anthropometrist (ISAK). Eight skinfolds (biceps, triceps, subscapular, suprailiac, supraspinatus, abdominal, anterior thigh, and medial calf), six circumferences (relaxed and contracted arm, waist, hip, thigh, and calf), and three bone diameters (humerus, biestylod, and femur) were evaluated according to the guidelines defined by the International Society for the Advancement of Kinanthropometry. A Slim Guide skinfold caliper (1 mm sensitivity) (Mexico), a caliper with larger and smaller diameters, a metal tape measure (1 mm sensitivity), and a Cescor® segmentometer with an accuracy of 0.1 cm (Porto Alegre, Brazil) were used. Measurements were taken in duplicate to minimize technical error (Adão et al., 2005). In addition, Carter and Heath's equations (Carter, 2002) were used to calculate the anthropometric somatotypes of the athletes.

### Procedure

The managers, coaching staff, and tutors of the cyclists signed the informed consent form. The test date was then agreed upon with the coaches of each category. Prior to the tests, the researchers conducted several pilot sessions to familiarize the athletes with the tests and the strict monitoring procedures, thereby reducing the possibility of errors during the evaluation.

The cyclists were summoned 15 minutes before the start of the evaluations in order to explain the procedures in detail. The tests began with anthropometric measurements, followed by the incremental exercise test. Participants were instructed to refrain from physical activity the day before the evaluations. The evaluations were carried out on different days. Similarly, diet, hydration, and pre-training time were adjusted at least 48 hours in advance to avoid the negative effects of accumulated fatigue. At the end of the physical tests, the research team downloaded the data to a laptop and imported it to obtain the variables. The data were exported to an Excel spreadsheet, and a database was created in Excel before entering them into the statistical package for further analysis.

### Protocol implemented

The maximum oxygen consumption test was performed at 2600 meters above sea level (Wasserman protocol), an incremental test that begins with a warm-up at 50W for 6 minutes. At the start of the test, the power was set to 60W, increasing by 20W every minute until the athlete voluntarily reached exhaustion. Diagnostic and control equipment (Tacx Flux simulator, Metalyzer 3B ergospirometer) was used to adjust it to the bicycle that each athlete normally uses. All evaluations were always carried out at the same time (from 8:00 a.m. to 12:00 p.m.) under controlled conditions (average temperature: 22-23°C; humidity: 77-83%). The evaluation was divided into two phases. The first phase involved ergospirometric evaluation of the athletes between January and February, and the second phase involved anthropometric measurements between February and March 2024. Three people per day were evaluated in ergospirometry (one day per week), and four athletes per day were evaluated in anthropometry during the period described above. The athletes were organized into groups and summoned 30 minutes before the evaluation to perform the different tests. At the end of each test, the research team downloaded the data to a laptop and imported it to obtain the variables under study. This data was exported to a spreadsheet to create a database in Excel before being entered into the statistical package for the respective analysis.

### Statistical analysis

The results of the different tests performed on the cyclists are described as mean and standard deviation (SD). The normality and homoscedasticity of the data were confirmed using the Shapiro-Wilk test, the results of which showed that the data did not follow a normal distribution. To compare each variable, a normality and homogeneity test was used on the data; those that met the criteria were subjected to an ANOVA test, with an  $n^2$  effect measure for the means and standard deviation; those that did not meet the criteria were compared using the nonparametric Kruskal-Wallis test, which compares medians. In this case, the median and its interquartile ranges are presented; the effect size was measured using the  $\varepsilon$  parameter. The following p values were established (\*  $p < 0.05$ ). All analyses were performed using RStudio software version 4.1.0 (RStudio, INC, Boston, MA, USA, 2016).

### Results

No significant differences were reported for the ergospirometric assessment variables of the athletes evaluated. The effect size was large ( $\eta^2 = 0.143$ ), indicating that 14.3% of the variability in Vo2/HR (ml) is explained by the category. The effect size was moderate ( $\eta^2 = 0.139$ ), indicating that 13.9% of the variability in Vo2/HR (ml) is explained by the category. The effect size was large ( $\eta^2 = 0.176$ ), indicating that 17.6% of the variability in Vo2/HR (ml) is explained by category. The effect size was moderate ( $\eta^2 = 0.127$ ), indicating that 12.7% of the variability in RR (/min) is explained by category. The effect size was large ( $\eta^2 = 0.174$ ), indicating that 17.4% of the variability in Vo2 (L/min) is explained by the category (Table 2).

The variables that showed significant differences were relaxed arm (cm) ( $p = 0.02$ ,  $\varepsilon^2: 0.29$ ). The effect size was large ( $\varepsilon^2 = 0.290$ ), indicating that 29.0% of the variability in relaxed arm circumference (cm) is explained by the category. Flexed arm (cm) ( $p=0.04$ ,  $\text{Eta}^2:0.29$ ). The effect size was large ( $\eta^2 = 0.292$ ), indicating that 29.2% of the variability in flexed arm circumference (cm) is explained by the category. Calf (cm) ( $p=0.03$ ,  $\text{Eta}^2:0.31$ ). The effect size was large ( $\eta^2 = 0.315$ ), indicating that 31.5% of the variability in calf circumference (cm) is explained by category (Table 3).

Table 2. Descriptive and inferential analysis of differences related to ergospirometry variables

| Test | Variable              | 15-16<br>(SD) | 17-19 (SD) | 20-25 (SD) | p    | Effect<br>Type   | Effect<br>value | Interpretation                                                                                                                               |
|------|-----------------------|---------------|------------|------------|------|------------------|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| VT1  | Vo2 (L/min)           | 2.19±0.34     | 2.43±0.3   | 2.47±0.4   | 0.51 | Eta <sup>2</sup> | 0.07            | The effect size was moderate ( $\eta^2 = 0.071$ ), indicating that 7.1% of the variability in Vo2 (L/min) is explained by category.          |
|      | Vo2/kg<br>(ml/min/kg) | 39.1±5.79     | 38.71±4.1  | 39.5±5.4   | 0.98 | Eta <sup>2</sup> | 0.00            | The effect size was negligible ( $\eta^2 = 0.002$ ), indicating that 0.2% of the variability in Vo2/kg (ml/min/kg) is explained by category. |
|      | Vo2/HR<br>(ml)        | 14.2±1.95     | 16.71±2.1  | 16±2.2     | 0.24 | Eta <sup>2</sup> | 0.14            | The effect size was large ( $\eta^2 = 0.143$ ), indicating that 14.3% of the variability in Vo2/HR (ml) is explained by category.            |
|      | WR (w)                | 167.3±33.9    | 169.2±20.2 | 170.8±44.4 | 0.99 | Eta <sup>2</sup> | 0.00            | The effect size was negligible ( $\eta^2 = 0.001$ ), indicating that 0.1% of the variability in WR (w) is explained by category.             |
|      | HR (/min)             | 154±6.8       | 147.2±12.1 | 151.5±11.4 | 0.63 | Eta <sup>2</sup> | 0.04            | The effect size was small ( $\eta^2 = 0.049$ ), indicating that 4.9% of the variability in HR (/min) is explained by category.               |
|      | VE/Vo2                | 28.0±1.6      | 27.26±1.2  | 27.3±1.1   | 0.71 | Eta <sup>2</sup> | 0.03            | The effect size was small ( $\eta^2 = 0.037$ ), indicating that 3.7% of the variability in VE/Vo2 is explained by category.                  |
|      | VE/VCO2               | 29.6±1.4      | 29.43±1.4  | 28.7±0.9   | 0.67 | Eta <sup>2</sup> | 0.04            | The effect size was small ( $\eta^2 = 0.043$ ), indicating that 4.3% of the variability in VE/VCO2 is explained by category.                 |
|      | RER                   | 0.95±0.0      | 0.93±0.0   | 0.95±0.0   | 0.52 | Eta <sup>2</sup> | 0.06            | The effect size was moderate ( $\eta^2 = 0.069$ ), indicating that 6.9% of the variability in                                                |

|                 |                    |                       |                        |                        |      |                  |      | RER is explained by category.                                                                                                              |
|-----------------|--------------------|-----------------------|------------------------|------------------------|------|------------------|------|--------------------------------------------------------------------------------------------------------------------------------------------|
| VT2             | VE (L/min)         | 65.9±8.3              | 70.7±10.7              | 71.9±12.3              | 0.68 | Eta <sup>2</sup> | 0.04 | The effect size was small ( $\eta^2 = 0.042$ ), indicating that 4.2% of the variability in VE (L/min) is explained by category.            |
|                 | RR (/min)          | 35.1±3.0              | 33.14±3.8              | 35 ± 4.9               | 0.72 | Eta <sup>2</sup> | 0.03 | The effect size was small ( $\eta^2 = 0.035$ ), indicating that 3.5% of the variability in RR (/min) is explained by category.             |
|                 | Vo2 (L/min)        | 3.19±0.5              | 3.41±0.5               | 3.66 ± 0.2             | 0.43 | Eta <sup>2</sup> | 0.08 | The effect size was moderate ( $\eta^2 = 0.087$ ), indicating that 8.7% of the variability in Vo2 (L/min) is explained by category.        |
|                 | Vo2/kg (ml/min/kg) | 56±8.3                | 55±8.39                | 59.1±3.7               | 0.75 | Eta <sup>2</sup> | 0.03 | The effect size was small ( $\eta^2 = 0.031$ ), indicating that 3.1% of the variability in Vo2/kg (ml/min/kg) is explained by category.    |
|                 | Vo2/HR (ml)        | 17.5±2.6              | 19.57±2.9              | 20.5±1.4               | 0.26 | Eta <sup>2</sup> | 0.13 | The effect size was moderate ( $\eta^2 = 0.139$ ), indicating that 13.9% of the variability in Vo2/HR (ml) is explained by category.       |
|                 | WR (w)             | 249±36.7              | 259.2±39.8             | 264.1±26.4             | 0.83 | Eta <sup>2</sup> | 0.02 | The effect size was small ( $\eta^2 = 0.020$ ), indicating that 2.0% of the variability in WR (w) is explained by category.                |
|                 | HR (/min)          | 179.5±7.6             | 174.8±7.2              | 178.8±6.7              | 0.64 | Eta <sup>2</sup> | 0.04 | The effect size was small ( $\eta^2 = 0.048$ ), indicating that 4.8% of the variability in HR (/min) is explained by category.             |
|                 | VE/Vo2             | 34.45 (29.08 - 39.2)  | 30.4 (30.25 - 34.5)    | 32.55 (30.75 - 37.27)  | 0.61 | e <sup>2</sup>   | 0    | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in VE/Vo2 is explained by category.       |
|                 | VE/VCO2            | 31.8±2.5              | 31.1±2.0               | 32.2±3.8               | 0.85 | Eta <sup>2</sup> | 0.01 | The effect size was small ( $\eta^2 = 0.017$ ), indicating that 1.7% of the variability in VE/VCO2 is explained by category.               |
|                 | RER                | 1.09±0.0              | 1.08±0.1               | 1.1±0.0                | 0.96 | Eta <sup>2</sup> | 0.00 | The effect size was negligible ( $\eta^2 = 0.005$ ), indicating that 0.5% of the variability in RER is explained by category.              |
| Vo2 Max or peak | VE (L/min)         | 99.45 (92.98 - 128.8) | 112.4 (99.55 - 147.95) | 123.1 (119.42 - 142.3) | 0.23 | e <sup>2</sup>   | 0.04 | The effect size was small ( $\epsilon^2 = 0.045$ ), indicating that 4.5% of the variability in VE (L/min) is explained by category.        |
|                 | RR (/min)          | 45 (41.75 - 49.25)    | 43 (40.5 - 47.5)       | 51.5 (48.75 - 53.5)    | 0.09 | e <sup>2</sup>   | 0.13 | The effect size was moderate ( $\epsilon^2 = 0.132$ ), indicating that 13.2% of the variability in RR (/min) is explained by category.     |
|                 | Vo2 (L/min)        | 3.65±0.5              | 4.01±0.5               | 4.2±0.2                | 0.23 | Eta <sup>2</sup> | 0.14 | The effect size was large ( $\eta^2 = 0.149$ ), indicating that 14.9% of the variability in Vo2 (L/min) is explained by category.          |
|                 | Vo2/kg (ml/min/kg) | 64.7±6.8              | 63.57±6.4              | 69±4.1                 | 0.49 | Eta <sup>2</sup> | 0.07 | The effect size was moderate ( $\eta^2 = 0.076$ ), indicating that 7.6% of the variability in Vo2/kg (ml/min/kg) is explained by category. |
|                 | Vo2/HR (ml)        | 18.8±2.5              | 21±3.08                | 22.5±1.7               | 0.17 | Eta <sup>2</sup> | 0.17 | The effect size was large ( $\eta^2 = 0.176$ ), indicating that 17.6% of the variability in Vo2/HR (ml) is explained by category.          |
|                 | WR (w)             | 305.6±39.6            | 324.2±32.6             | 340.8±28               | 0.40 | Eta <sup>2</sup> | 0.09 | The effect size was moderate ( $\eta^2 = 0.096$ ), indicating that 9.6% of the variability in WR (w) is explained by category.             |
|                 | HR (/min)          | 193.6±3.7             | 190.1±2.7              | 191.5±5.3              | 0.45 | Eta <sup>2</sup> | 0.08 | The effect size was moderate ( $\eta^2 = 0.084$ ), indicating that 8.4% of the variability in HR (/min) is explained by category.          |
|                 | VE/Vo2             | 42.9±3.3              | 42.8±2.3               | 42.6±2.9               | 0.99 | Eta <sup>2</sup> | 0.00 | The effect size was negligible ( $\eta^2 = 0.001$ ), indicating that 0.1% of the variability in VE/Vo2 is explained by category.           |
|                 | VE/VCO2            | 35.7±2.1              | 35.7±1.5               | 36.4±2.7               | 0.88 | Eta <sup>2</sup> | 0.01 | The effect size was small ( $\eta^2 = 0.013$ ), indicating that 1.3% of the variability in VE/VCO2 is explained by category.               |
|                 | RER                | 1.2±0.0               | 1.2±0.0                | 1.1±0.0                | 0.56 | Eta <sup>2</sup> | 0.06 | The effect size was moderate ( $\eta^2 = 0.061$ ), indicating that 6.1% of the variability in RER is explained by category.                |
| Vo2 peak % prev | VE (L/min)         | 166.8±29              | 179.6±29.1             | 192.2±12.9             | 0.43 | Eta <sup>2</sup> | 0.08 | The effect size was moderate ( $\eta^2 = 0.089$ ), indicating that 8.9% of the variability in VE (L/min) is explained by category.         |
|                 | RR (/min)          | 65.7±5.8              | 64.86±7.3              | 72.1±6.3               | 0.29 | Eta <sup>2</sup> | 0.12 | The effect size was moderate ( $\eta^2 = 0.127$ ), indicating that 12.7% of the variability in RR (/min) is explained by category.         |
|                 | Vo2 (L/min)        | 139.2±8.7             | 143.4±7.6              | 147±12.5               | 0.54 | Eta <sup>2</sup> | 0.06 | The effect size was moderate ( $\eta^2 = 0.066$ ), indicating that 6.6% of the variability in Vo2 (L/min) is explained by category.        |
|                 | Vo2/kg (ml/min/kg) | 139.2±8.7             | 143.4±7.6              | 147±12.5               | 0.54 | Eta <sup>2</sup> | 0.06 | The effect size was moderate ( $\eta^2 = 0.066$ ), indicating that 6.6% of the variability in Vo2/kg (ml/min/kg) is explained by category. |
|                 | Vo2/HR (ml)        | 133.1±9.7             | 138.2±8.0              | 138±13.4               | 0.72 | Eta <sup>2</sup> | 0.03 | The effect size was small ( $\eta^2 = 0.035$ ), indicating that 3.5% of the variability in Vo2/HR (ml) is explained by category.           |
|                 | WR (w)             | 133.5±12.2            | 133±16.8               | 131±17.6               | 0.97 | Eta <sup>2</sup> | 0.00 | The effect size was negligible ( $\eta^2 = 0.003$ ), indicating that 0.3% of the variability in WR (w) is explained by category.           |
|                 | HR (/min)          | 105±2.1               | 103.7±1.7              | 106.6±1.8              | 0.16 | Eta <sup>2</sup> | 0.18 | The effect size was large ( $\eta^2 = 0.184$ ), indicating that 18.4% of the variability in HR (/min) is explained by category.            |
|                 | VE (L/min)         | 174.7±22.4            | 177±14.9               | 178.5±10.7             | 0.95 | Eta <sup>2</sup> | 0.00 | The effect size was negligible ( $\eta^2 = 0.005$ ), indicating that 0.5% of the variability in                                            |

|                   |                    |                 |                  |                     |      |                  |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------|--------------------|-----------------|------------------|---------------------|------|------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Abs<br>Max<br>val | RR (/min)          | 158.5±11.4      | 157.8±16.2       | 169.8±15.5          | 0.47 | Eta <sup>2</sup> | 0.08 | VE (L/min) is explained by category.<br>The effect size was moderate ( $\eta^2 = 0.080$ ), indicating that 8.0% of the variability in RR (/min) is explained by category.<br>The effect size was large ( $\eta^2 = 0.174$ ), indicating that 17.4% of the variability in Vo2 (L/min) is explained by category.<br>The effect size was moderate ( $\eta^2 = 0.093$ ), indicating that 9.3% of the variability in Vo2/KG (ml/min/kg) is explained by category.<br>The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Vo2/HR (ml) is explained by category.<br>The effect size was large ( $\eta^2 = 0.170$ ), indicating that 17.0% of the variability in WR (w) is explained by category.<br>The effect size was moderate ( $\eta^2 = 0.097$ ), indicating that 9.7% of the variability in HR (/min) is explained by category.<br>The effect size was moderate ( $\eta^2 = 0.063$ ), indicating that 6.3% of the variability in VE/Vo2 is explained by category.<br>The effect size was small ( $\eta^2 = 0.017$ ), indicating that 1.7% of the variability in VE/VCO2 is explained by category.<br>The effect size was moderate ( $\eta^2 = 0.076$ ), indicating that 7.6% of the variability in RER is explained by category.<br>The effect size was moderate ( $\eta^2 = 0.126$ ), indicating that 12.6% of the variability in VE (L/min) is explained by category. |
|                   | Vo2 (L/min)        | 3.84±0.5        | 4.23±0.6         | 4.56±0.2            | 0.18 | Eta <sup>2</sup> | 0.17 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | Vo2/kg (ml/min/kg) | 68.1±6.6        | 67.2±7.6         | 73.8±6.2            | 0.41 | Eta <sup>2</sup> | 0.09 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | Vo2/HR (ml)        | 22 (20.25 - 24) | 22 (21.5 - 26.5) | 23.5 (22.25 - 25.5) | 0.50 | e <sup>2</sup>   | 0    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | WR (w)             | 311.5±40.8      | 332.8±23.4       | 361±37              | 0.18 | Eta <sup>2</sup> | 0.17 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | HR (/min)          | 195.3±3.8       | 191.2±3.0        | 194±5.9             | 0.40 | Eta <sup>2</sup> | 0.09 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | VE/Vo2             | 51.3±7.6        | 49.6±6           | 46.3±3.1            | 0.55 | Eta <sup>2</sup> | 0.06 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | VE/VCO2            | 40.5±3.5        | 40.3±2.6         | 39.3±2.8            | 0.85 | Eta <sup>2</sup> | 0.01 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | RER                | 1.26±0.0        | 1.23±0.1         | 1.1±0.0             | 0.49 | Eta <sup>2</sup> | 0.07 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                   | VE (L/min)         | 176.8±29.4      | 190.0±28.7       | 207.7±10.7          | 0.29 | Eta <sup>2</sup> | 0.12 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

Note: SD: standard deviation; VT1: first ventilatory threshold; VT2: second ventilatory threshold; VO<sub>2</sub>: oxygen consumption; VO<sub>2</sub>/kg: oxygen consumption relative to body mass; VO<sub>2</sub>/HR: oxygen pulse; WR: work rate; HR: heart rate; VE: minute ventilation; VCO<sub>2</sub>: carbon dioxide production; VE/VO<sub>2</sub>: ventilatory equivalent for oxygen; VE/VCO<sub>2</sub>: ventilatory equivalent for carbon dioxide; RER: respiratory exchange ratio; RR: respiratory rate; L/min: liters per minute; /min: beats or breaths per minute; ml: milliliters; W: watts;  $\epsilon^2$ : epsilon squared;  $\eta^2$ : eta squared; mm: millimeters; cm: centimeters; kg: kilograms; %: percentage; \* indicates statistically significant differences ( $p < 0.05$ ).

**Table 3.** Descriptive and inferential analysis of differences related to anthropometric variables.

| Variable                    | 15-16 years<br>SD – IC | 17-19 years (m<br>SD – IC) | 20-25 years (m -<br>SD – IC) | p    | Effect<br>Type   | Effect<br>value | Interpretation                                                                                                                                          |
|-----------------------------|------------------------|----------------------------|------------------------------|------|------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fat mass -<br>Faulkner (%)  | 10.91 (9.95 - 21.42)   | 11 (10.51 -<br>16.98)      | 11.3 (9.17 - 13.65)          | 0.91 | e <sup>2</sup>   | 0               | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Fat mass - Faulkner (%) is explained by category.   |
| Fat mass -<br>Faulkner (kg) | 7.7±2.6                | 7.5±2.8                    | 7.8±2.8                      | 0.99 | Eta <sup>2</sup> | 0.00            | The effect size was negligible ( $\eta^2 = 0.001$ ), indicating that 0.1% of the variability in Fat mass - Faulkner (kg) is explained by category.      |
| Fat mass - Carter<br>(%)    | 7.79 (7.1 - 17.82)     | 8 (7.35 - 13.62)           | 7.88 (5.84 - 9.3)            | 0.91 | e <sup>2</sup>   | 0               | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Fat mass - Carter (%) is explained by category.     |
| Fat mass - Carter<br>(kg)   | 5.9±2.6                | 5.7±3.0                    | 5.7±2.8                      | 0.99 | Eta <sup>2</sup> | 0.00            | The effect size was negligible ( $\eta^2 = 0.001$ ), indicating that 0.1% of the variability in Fat mass - Carter (kg) is explained by category.        |
| Triceps (mm)                | 7.65 (6.82 - 14.62)    | 6.7 (5.9 - 17.5)           | 7.15 (5.72 - 13.07)          | 0.86 | e <sup>2</sup>   | 0               | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Triceps Skinfold (mm) is explained by category.     |
| Subscapular (mm)            | 9.35 (7.72 - 17.38)    | 11 (9.25 - 18.5)           | 10.75 (7.88 - 16.25)         | 0.64 | e <sup>2</sup>   | 0               | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Subscapular Skinfold (mm) is explained by category. |
| Biceps (mm)                 | 4.25 (3 - 6.28)        | 4 (3.35 - 7.15)            | 4 (3.25 - 5.5)               | 0.81 | e <sup>2</sup>   | 0               | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Biceps Skinfold (mm) is explained by category.      |
| Iliac Crest (mm)            | 12.9 (9.68 - 17.38)    | 15 (12.5 - 25)             | 9.75 (7.85 - 19)             | 0.34 | e <sup>2</sup>   | 0.00            | The effect size was negligible ( $\epsilon^2 = 0.007$ ), indicating that 0.7% of the variability in Iliac Crest Skinfold (mm) is explained by category. |
| Supraespal (mm)             | 7.75 (6.58 - 13.85)    | 9.3 (7.65 - 17)            | 10.65 (6.1 - 14.75)          | 0.72 | e <sup>2</sup>   | 0               | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Supraespal Skinfold (mm) is explained by category.  |

|                  |                     |                     |                      |       |                  |      |                                                                                                                                                          |
|------------------|---------------------|---------------------|----------------------|-------|------------------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Abdominal (mm)   | 13.0±4.0            | 15.1±6.1            | 16.3±6.3             | 0.69  | Eta <sup>2</sup> | 0.03 | The effect size was small ( $\eta^2 = 0.039$ ), indicating that 3.9% of the variability in Abdominal Skinfold (mm) is explained by category.             |
| Thigh (mm)       | 11 (8.93 - 15.2)    | 10 (8.9 - 19.75)    | 9.85 (8.65 - 16)     | 0.82  | e <sup>2</sup>   | 0    | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Thigh Skinfold (mm) is explained by category.        |
| Calf (mm)        | 7.25 (5.95 - 12.62) | 7 (5.65 - 15.25)    | 6 (4.85 - 12.93)     | 0.72  | e <sup>2</sup>   | 0    | The effect size was negligible ( $\epsilon^2 = 0.000$ ), indicating that 0.0% of the variability in Calf Skinfold (mm) is explained by category.         |
| Relaxed Arm (cm) | 24.6 (24.17 - 25.2) | 25.2 (25.05 - 28.9) | 26.8 (26.52 - 27.75) | 0.02* | e <sup>2</sup>   | 0.29 | The effect size was large ( $\epsilon^2 = 0.290$ ), indicating that 29.0% of the variability in Relaxed Arm Circumference (cm) is explained by category. |
| Flexed Arm (cm)  | 26.0±1.36           | 28.9±2.3            | 29.0±1.6             | 0.04* | Eta <sup>2</sup> | 0.29 | The effect size was large ( $\eta^2 = 0.292$ ), indicating that 29.2% of the variability in Flexed Arm Circumference (cm) is explained by category.      |
| Waist (cm)       | 67.8±2.5            | 73.1±3.9            | 71.5±2.8             | 0.07  | Eta <sup>2</sup> | 0.25 | The effect size was large ( $\eta^2 = 0.250$ ), indicating that 25.0% of the variability in Waist Circumference (cm) is explained by category.           |
| Hip (cm)         | 89.1±1.9            | 91.7±4.7            | 91.6±4.1             | 0.51  | Eta <sup>2</sup> | 0.07 | The effect size was moderate ( $\eta^2 = 0.070$ ), indicating that 7.0% of the variability in Hip Circumference (cm) is explained by category.           |
| Mid-thigh (cm)   | 48.4±1.7            | 51.4±2.6            | 51.4±0.8             | 0.06  | Eta <sup>2</sup> | 0.25 | The effect size was large ( $\eta^2 = 0.259$ ), indicating that 25.9% of the variability in Mid-thigh Circumference (cm) is explained by category.       |
| Calf (cm)        | 32.2±1.1            | 34.5±1.6            | 34.5±0.9             | 0.03* | Eta <sup>2</sup> | 0.31 | The effect size was large ( $\eta^2 = 0.315$ ), indicating that 31.5% of the variability in Calf Circumference (cm) is explained by category.            |
| Humerus (mm)     | 6.3±0.32            | 6.9±0.4             | 6.6±0.4              | 0.12  | Eta <sup>2</sup> | 0.20 | The effect size was large ( $\eta^2 = 0.207$ ), indicating that 20.7% of the variability in Humerus Diameter (mm) is explained by category.              |
| Biastyloid (mm)  | 5.2±0.26            | 5.7±0.5             | 5.5±0.4              | 0.21  | Eta <sup>2</sup> | 0.15 | The effect size was large ( $\eta^2 = 0.159$ ), indicating that 15.9% of the variability in Biastyloid Diameter (mm) is explained by category.           |
| Femur (mm)       | 8.9±0.4             | 9.4±0.4             | 9.1±0.4              | 0.20  | Eta <sup>2</sup> | 0.16 | The effect size was large ( $\eta^2 = 0.163$ ), indicating that 16.3% of the variability in Femur Diameter (mm) is explained by category.                |

Note: SD: standard deviation;  $\epsilon^2$ : epsilon squared;  $\eta^2$ : eta squared; mm: millimeters; cm: centimeters; kg: kilograms; %: percentage; \*: indicates statistically significant differences ( $p < 0.05$ ).

## Discussion

The objective of this research was to characterize the physiological and anthropometric profile of Mtb-Xco mountain bikers in the U-15, U-17, and U-20 categories. A total of 21 athletes were evaluated, analyzing their physiological and mechanical response in an incremental test with ergospirometry and their morphological characteristics through body measurements in trained cyclists. The findings of this study are consistent with research that has reported the importance of analyzing variables such as Vo2max, mechanical power, and ventilatory thresholds to understand the athletic performance of mountain bikers (Hebisz et al., 2017; Hebisz et al., 2018). However, few studies have evaluated physiological and anthropometric components in the same study to determine differences between categories (Fornasiero et al., 2018). It should be noted that, in the South American context, there is limited production of studies with this type of objective, so this would be one of the first investigations based on the characterization of athletic performance in Colombian mountain bikers.

The most relevant results based on the effect size associated with physiological and mechanical variables were: Vo2max and maximum power in the maximum values of the incremental test with moderate-large effect sizes ( $\eta^2$  or  $\epsilon^2$ ), as well as Vo2HR, which reported differences between categories in VT1, VT2, and Vo2max. In contrast, the variables VE, VE/VCO2, and VE/Vo2 presented small or moderate effect sizes and no significant values. Regarding the components of the anthropometry variable, significant differences ( $p < 0.05$ ) were found in the circumference of the relaxed arm ( $p < 0.02$ ), flexed arm ( $p < 0.04$ ), and calf circumference

( $p < 0.03$ ). However, the impact of these variables on performance appears to be less significant compared to physiological and mechanical variables.

#### *Physiological profile variables*

The report by Hays et al. (2018) describes the understanding of physiological requirements in Mtb-Xco tests in 16 mountain bikers aged between 17 and 23, where  $\text{Vo}_2$  was monitored continuously, and it was identified that the cumulative time in different work zones is not considered to be related to heart rate (slow response to stimuli) or mechanical power (instantaneous response measured at the crank). In contrast, our findings indicate that it is important to consider the values obtained from  $\text{Vo}_{2\text{max}}$  and  $\text{Vo}_{2\text{HR}}$  as more stable indicators for determining oxygen utilization capacity between categories. In the U-15, U-17, and U-20 categories, the most decisive variables in the different periods of the incremental test were  $\text{Vo}_{2\text{max}}$ ,  $\text{Vo}_{2\text{HR}}$ , and WR, which were the most relevant variables for differentiating the data collected between age groups, allowing for discussion with some background information.

In a systematic review of endurance sports, they observed changes associated with maximum oxygen consumption based on a polarized training program, where they found that eight of the included studies showed improvements in  $\text{Vo}_{2\text{max}}$  or  $\text{Vo}_{2\text{peak}}$  (+29.9%,  $p = 0.01$ ,  $d = 0.16$ ) with interventions lasting longer than 12 weeks (Nøst et al., 2024). Similarly, shorter protocols, such as those lasting nine weeks, showed significant improvements (+11.7%,  $p < 0.001$ ) (Stöggl & Sperlich, 2014), and even eight-week interventions showed increases of +2.1%,  $p < 0.05$ ,  $d = 0.40$  (Filipas et al., 2022).

More specifically, reports on cyclists concluded improvements of +6.5%,  $p = 0.027$ ,  $d = 0.95$  (Selles-Perez et al., 2019). Although this study did not have a longitudinal cut-off, it is important to recognize the absolute or maximum values of mountain bikers to determine training thresholds depending on the category, with the U-15 category reporting  $68.1 \pm 6.6$  ml/kg/min, which is better than the U-17 category with  $67.2 \pm 7.6$  ml/kg/min and lower than the U-20 category with values of  $73.8 \pm 6.2$  ml/kg/min, the latter having the best  $\text{Vo}_{2\text{max}}$  performance. It should be noted that despite the difference in data, no significant differences were observed between categories, but with moderate effect sizes ( $p = 0.51$ ;  $\eta^2 = 0.07$ ).

Previous studies have mentioned physiological variables in an official simulated test and a real test, providing evidence of the demands placed on mountain bikers, which conclude that it is an intermittent sport with aerobic and anaerobic contributions, spending most of the time above VT1 with demands of 87% of  $\text{Vo}_{2\text{max}}$  (Hays et al., 2018). Therefore, in relation to the results obtained in VT1, the variables were similar between the different age groups and presented  $\text{Vo}_{2\text{max}}$  values in the U-15 of ( $2.19 \pm 0.34$  L/min), U-17 of ( $2.43 \pm 0.30$  L/min), and U-20 of ( $2.47 \pm 0.40$  L/min) with statistically non-significant values ( $p = 0.51$ ) but with a moderate effect size ( $\eta^2 = 0.07$ ), while relative  $\text{Vo}_2$  showed ( $p = 0.98$ ;  $\eta^2 = 0.00$ ), indicating that body mass further reduces the differences between categories. In this case, although cyclists remain largely above VT1 in competition, this threshold does not allow for precise differentiation in youth categories in an incremental test. Therefore, data on this parameter does not appear to be a sensitive indicator of performance, but rather that significant differences arise mainly at maximum intensities.

In a study conducted by Smekal et al. (2015), simulated and laboratory tests were also carried out, using a high-performance athlete as a parameter for comparison with the research sample. In this comparative study, the high-performance cyclist achieved  $\text{Vo}_{2\text{peak}}$  values of  $79.9$  ml·kg<sup>-1</sup>·min<sup>-1</sup> when he recorded  $48.1$  ml·kg<sup>-1</sup>·min<sup>-1</sup> at VT1 and  $64.4$  ml·kg<sup>-1</sup>·min<sup>-1</sup> at VT2, compared to the sample group, which reported  $\text{Vo}_2$  peak values of  $64.9 \pm 7.5$ , with  $34.6 \pm 7.1$  ml·kg<sup>-1</sup>·min<sup>-1</sup> at VT1 and  $50.8 \pm 6.6$  ml·kg<sup>-1</sup>·min<sup>-1</sup> at VT2, which initially highlights the difference between a high-performance mountain biker and one in training. Our results at the maximum values show the following data: U-15 ( $64.7 \pm 6.8$  ml·kg<sup>-1</sup>·min<sup>-1</sup>), U-17 ( $63.57 \pm 6.4$  ml·kg<sup>-1</sup>·min<sup>-1</sup>) and U-20 ( $69 \pm 4.1$  ml·kg<sup>-1</sup>·min<sup>-1</sup>) in  $\text{Vo}_{2\text{max}}$  with a moderate effect size ( $\eta^2 = 0.093$ ), which allows comparison with a classification in the range of trained youth cyclists. Although older cyclists had better values compared to younger cyclists and those closer to elite U23 athletes, the physiological parameters still correspond mainly to athletes in training, clarifying that our study reports the  $\text{Vo}_{2\text{max}}$  variable and the study by Smekal et al. (2015) reports  $\text{Vo}_{2\text{peak}}$ .

Another study, one of the first conducted on mountain bikers, by Impellizzeri et al. (2005), yielded  $\text{Vo}_{2\text{max}}$  results in laboratory tests with values of  $5.11 \pm 0.46$  L/min and  $76.9 \pm 5.3$  ml·kg<sup>-1</sup>·min<sup>-1</sup> with an average age of  $24.9 \pm 2.9$  years, in adult and highly trained cyclists achieving the maximum expected point in the physiological profile of highly competitive level. In addition, older cyclists had mean  $\text{VO}_2$  values at VT2 of  $56.8 \pm 4.8$  ml·kg<sup>-1</sup>·min<sup>-1</sup>. When comparing these data with our results, they were very similar in this test period:  $56$  ml·kg<sup>-1</sup>·min<sup>-1</sup> in U15,  $55$  ml·kg<sup>-1</sup>·min<sup>-1</sup> in U17, and  $59.1$  ml·kg<sup>-1</sup>·min<sup>-1</sup> in U20, with no significant differences between groups and a small effect size. This finding suggests that, unlike  $\text{Vo}_{2\text{max}}$ , VT2 seems to have similar results among youth categories, and may even approximate that of older, highly trained cyclists.

To our knowledge, previous studies such as those by Impellizzeri et al. (2005), Smekal et al. (2015), and Hebisz et al. (2022) have evaluated  $\text{Vo}_{2\text{max}}$  using incremental tests or comparisons between methods; however, none of them have reported  $\text{VO}_2/\text{HR}$  as a central physiological indicator. Although heart rate is a delayed indicator of the stimulus to which the athlete is subjected (Hays et al., 2018), in our data, this variable showed the most relevant data, passing through VT1 ( $\eta^2 = 0.14$ ), VT2 ( $\eta^2 = 0.13$ ), and  $\text{Vo}_{2\text{max}}$  ( $\eta^2 = 0.17$ ),

showing an increase in all stages of the test, being higher in U-20 considering that in absolute maximum values the effect is null ( $\epsilon^2 = 0.0$ ), which seems to indicate that  $\text{Vo}_2/\text{HR}$  between categories is a fundamental parameter in specific intensities between categories.

#### *Anthropometric profile variables*

In relation to anthropometric profile, multiple forms have been recorded in different studies (Warner et al., 2002; Lee et al., 2002; Mirizio et al., 2021). Among the first basic measurements, cyclists ranging from 175 to 180 cm in height and weighing between 65 and 72 kg have been reported (Mirizio et al., 2022). In contrast to our results, measurements lower than those reported were found according to age: U-15 (167.85 cm), U-17 (169.8 cm), and U-20 (166.5 cm). Likewise, in terms of total body mass, the results indicate differences for U-15 (56.55 kg), U-17 (63.01 kg), and U-20 (60.47 kg) that point to the process of growth and consolidation of the athlete's morphofunctional structure.

When comparing other anthropometric variables with some reported research, there are some differences associated with body composition based on the maturity of the mountain biker. In the study by Mirizio et al. (2021), they developed a methodology that groups information into five categories (adiposity, musculature, residual, skeletal, and skin) with an age of  $16.3 \pm 0.95$  years, a body mass of  $67.22 \pm 7.49$ , an absolute fat mass of  $15.26 \pm 1.43$  kg ( $22.91 \pm 2.6\%$ ), and the sum of skinfolds reported  $47.71 \pm 8.24$ , reflecting a higher level of absolute fat tissue. In contrast, our results showed lower fat mass data, estimated by Faulkner at between 10.91% and 11.3% and by Carter at between 7.79% and 8%, with absolute values remaining in a range between 5.7 and 7.8 kg without significant differences and with a low effect size ( $\eta^2 = 0.0$ ).

These differences in the results suggest that the mountain bikers evaluated, despite demonstrating a low percentage of fat and no differences between categories, do have a different morpho functional development compared to other population groups. Additionally, studies have reported the importance of analyzing fat in athletes, as it negatively affects the ability to generate relative maximum power (Carvalho de Moura et al., 2025), impairs the development of thermoregulation (Morrissey et al., 2021) and, as in other endurance sports, they have associated lower fat percentage values with better race times (Rüst et al., 2012). Likewise, this same variable shows no association with manual pressure, both in the dominant and non-dominant hand, with a minimum variance ( $R^2 = 0.003\text{--}0.072$ ).

Finally, the most relevant anthropometric results reported in the study were relaxed arm, flexed arm, and calf, with statistically significant differences and high effect size. The differences between categories in relaxed arm are observed in the U-15 (24.6 cm) to the U-20 (26.8 cm), explaining 29.0% of the variability attributable to the category ( $\epsilon^2 = 0.290$ ). Similarly, for flexed arm, it reported an explained variance ( $\eta^2 = 0.292$ ). However, the highest effect size was calf circumference ( $\eta^2 = 0.315$ ), reflecting that cyclist generate structural adaptations in specific areas. Although the percentage of fat is similar across ages, circumferences appear to be more sensitive anthropometric markers of maturational development. These findings cannot be verified due to a lack of literature. Although bioimpedance methodologies have been developed (Carvalho de Moura et al., 2025), it is important to report other or more variables based on body composition.

#### *Limitations and future perspectives of the study*

This study has limitations that need to be reported for consideration in future research. First, it is essential to implement a more complete profile of mountain bikers to observe other variables associated with athletic performance. Although cross-sectional studies are essential for determining the characteristics of the population, cause and effect cannot be established. Secondly, the sample group is small, and although no significant differences were observed, a moderate-high effect size was obtained, limiting the statistical results. Therefore, it is important to consider more athletes for the intervention and, similarly, to begin to differentiate the physiological and anthropometric variables between gender. Furthermore, there is a need for longitudinal studies and randomized controlled trials to promote a better understanding of the physiological and anthropometric effects in these types of sports. It is also important to recognize that such research aims to provide insights to coaches, strength and conditioning specialists, technical staff, and other professionals, so that this knowledge can be applied to actual training and competition practices (Becerra Patiño & Escorcía-Clavijo, 2023).

#### **Conclusions**

Based on the objective set and the findings obtained, it can be concluded that the physiological profile continues to be one of the most relevant variables in mountain biking for differentiating performance between age categories, with absolute  $\text{VO}_2$ ,  $\text{VO}_2/\text{HR}$ , and maximum power at different points in the incremental test standing out. The most consistent differences were observed at maximum intensities. From an anthropometric perspective, body fat estimation did not represent a discriminating variable between categories, while relaxed arm, contracted arm, and calf circumferences showed significant bodily adaptations. Taken together, these findings indicate that performance development in young Mtb-Xco cyclists depends more on physiological adaptations and specific morphological changes than on body composition estimates, providing key information for the formative stages and planning of sports training.

**Funding.** This research received no external funding.

**Institutional Review Board Statement.** Technical staff and players were previously informed about the investigation details and signed informed consent. This study was performed based on the ethical guidelines of the World Medical Association (2025).

**Informed Consent Statement.** Informed consent was obtained from all the subjects involved in this study.

**Data Availability Statement.** The data presented in this study are available on request from the corresponding author.

**Acknowledgments.** The authors would like to thank the study participants, as well as the team staff, for their availability and commitment to this study.

**Conflicts of Interest.** The authors declare no conflicts of interest.

**Generative AI statement.** The authors declare that no Generative AI was used in the creation of this manuscript.

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