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PHASE ANGLE AND BODY COMPOSITION: MARKERS OF PHYSICAL PERFORMANCE IN MOUNTAIN BIKE ATHLETES

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ABSTRACT

Introduction: This study aimed to investigate the relationship between Phase angle (PhA) and body composition parameters with physical performance in national-level Mountain Bike (MTB) athletes. Materials and methods: Eighty-three male MTB athletes (age: 39.6 ±11.5 years) participated in the study. Body composition was assessed using a multi-tactile bioimpedance analyzer (InBody S10), while performance was evaluated through handgrip strength, standing long jump, and race completion time during a 75 km competition. Pearson's correlation was used to assess relationships between PhA, body composition, and performance variables. Results: Higher PhA values were associated with better handgrip strength (r >518; p<0.001), standing long jump performance (r=0.504; p=0.001). Notably, athletes with higher PhA completed the race in less time (r=-0.488; p<0.001). Secondarily, body fat, skeletal muscle mass, total body water and extracellular water rate were significantly associated with handgrip strength, standing long jump performance and race time (p<0.001). Conclusion: PhA, as well as body composition parameters including body fat, skeletal muscle mass, total body water, are promising markers of muscle strength and performance in MTB athletes. Therefore, these variables could be integrated into training programs to contribute to monitoring muscle integrity and optimizing athletic performance.

Key words: Bioimpedance. Muscle mass. Cycling. MTB.

RESUMO

Ângulo de fase e composição corporal: marcadores de desempenho físico em atletas de MTB

Introdução: Este estudo teve como objetivo investigar a relação entre o ângulo de fase (AF) e parâmetros de composição corporal com o desempenho físico em atletas de mountain bike (MTB) de nível nacional. Materiais e métodos: Oitenta e três atletas masculinos de MTB (idade: 39,6 ±11,5 anos) participaram do estudo. A composição corporal foi avaliada utilizando um analisador de bioimpedância multi-tátil (InBody S10), enquanto o desempenho foi mensurado através da força de preensão manual, salto horizontal e tempo de conclusão em uma competição de 75 km. A correlação de Pearson foi utilizada para avaliar as relações entre o AF, composição corporal e variáveis de desempenho. Resultados: Valores mais altos de AF foram associados a uma melhor força de preensão manual (r >0,518; p<0,001) e desempenho no salto horizontal (r = 0,504; p=0,001). Notavelmente, atletas com maior AF completaram a corrida em menos tempo (r= -0,488; p<0,001). Secundariamente, a gordura corporal, massa muscular esquelética, água corporal total e taxa de água extracelular apresentaram associação significativa com a força de preensão manual, desempenho no salto horizontal e tempo de corrida (p<0,001). Conclusão: O AF, assim como parâmetros de composição corporal, incluindo gordura corporal, massa muscular esquelética e água corporal total, são marcadores promissores de força muscular e desempenho em atletas de MTB. Portanto, essas variáveis poderiam ser integradas a programas de treinamento para contribuir com o monitoramento da integridade muscular e otimização do desempenho atlético.

Palavras-chave: Bioimpedância. Massa muscular. Ciclismo. MTB.

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INTRODUCTION

Cycling has become a sport of growing popularity and serves as both a recreational activity and a mode of transportation worldwide. It is generally divided into two primary categories: road (or street) cycling and mountain (or off-road) biking (UCI, 2024).

With over 30 million practitioners worldwide, mountain biking is a sport that involves riding bicycles off-road, often on rugged and challenging terrain (Schueller, 2010).

Mountain bikes, though diverse in design, typically feature wider tires with enhanced traction and suspension on the front wheel or both, offering greater stability compared to road bicycles (Ansari et al., 2017).

The sport demands a combination of endurance, strength, balance, and technical skills to navigate obstacles like rocks, roots, and steep descents (Stapelfeldt et al., 2004).

Monitoring and analyzing body composition is crucial in sports, as it is closely related to improvements in both aerobic and anaerobic performance, as well as muscle strength (Marini et al., 2020).

One of the prominent methods for assessing body composition is bioelectrical impedance analysis (BIA) (Nabuco et al., 2019), recognized for being safe, quick, and non-invasive, allowing its use across various populations. BIA measures bioimpedance, which is the result of bioelectrical resistance (R) and reactance (Xc) combined (Bongiovanni et al., 2020).

This approach facilitates the assessment of segmental body composition through predictive equations, estimating parameters such as fat-free mass (FFM), body cell mass, total body water, extracellular water, and intracellular water (Martins et al., 2019).

A more advanced application of BIA is bioelectrical impedance vector analysis (BIVA), which evaluates basic bioelectrical properties (Campa et al., 2023).

The electrical current passing through cell membranes, which act as capacitors, results in a phase shift known as the geometric phase angle (PhA) (Kyle et al., 2013).

PhA is calculated using the primary values of resistance (R) and reactance (Xc) from bioimpedance measurements. This parameter reflects the electrical properties of cell membranes and indicates the balance between intracellular and extracellular water in body compartments (Alves et al., 2022).

Factors such as age, gender, and body mass index (BMI) significantly influence PhA in healthy adults. With advancing age, PhA typically decreases as resistance rises due to a decline in body water ratio and an increase in fat mass.

Besides, men tend to exhibit a higher PhA compared to women, primarily due to greater muscle mass (Norman et al., 2012).

Thus, PhA has been widely used as an indicator of cell health, cell membrane integrity, and cell function, not only in the general population but also in athletes (Santos et al., 2021; Garlini et al., 2019; Martins et al., 2019; Nabuco et al., 2019; Silvino, Barros, et al., 2024).

The combined use of BIA and PhA in sports settings could be a valuable strategy for assessing changes in body composition and evaluating performance. We hypothesize that PhA body composition can serve as tools for coaches and athletes to estimate performance status in MTB athletes.

Consequently, the aim of this study is to examine the relationship between phase angle, body composition parameters, and sports performance in national-level mountain bikers.

MATERIALS AND METHODS

Participants

This study involved 83 male national-level MTB athletes aged between 18 to 65 years (mean age: 39.6 ± 11.5 years).

The participants were recruited from local mountain bike clubs. All participants had been training for at least one year, with a weekly volume of 150km.

They also regularly competed in regional and national events over the previous two years. Exclusion criteria included having chronic degenerative diseases, endocrine or thermoregulatory disorders, smoking, alcohol consumption, or taking medications or vitamin-mineral supplements that could affect hydroelectrolyte balance.

Participants with a history of health conditions or those consuming substances that could enhance performance or body composition were excluded from the study. All participants provided written informed consent in line with Resolution 466/12 of the National Health Council. The study received approval from the Research Ethics Committee Universidade Federal do Piaui, under protocol number 6.494.725.

Procedures

Firstly, participants performed anthropometric, body composition, and physical performance evaluations. One week later, their MTB racing performance was assessed during a real race event, with the race completion time recorded by the event organizers. A schematic overview of the experimental protocols is shown in Figure 1.

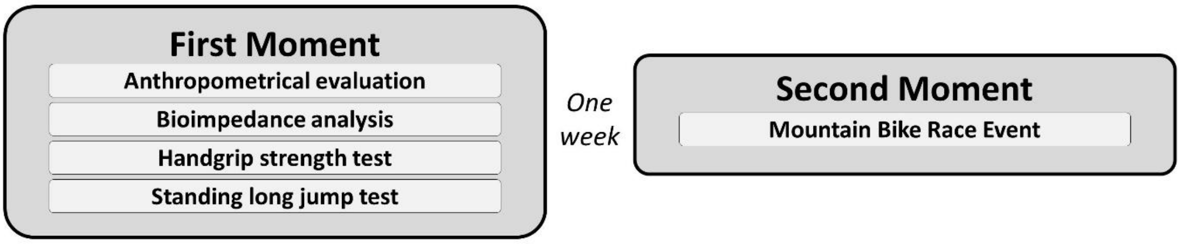

Figure 1 - Schematic view of the protocols used to assess the anthropometrical, body composition and physical performance parameters of the participants.

Anthropometric measures

Body mass was measured using a digital scale (Filizola, São Paulo, Brazil), with a capacity of 150 kg and a precision of 100 grams. Height was measured twice with participants in the anatomical position, using a portable stadiometer (Avanutri, São Paulo, Brazil) with an accuracy of 0.1 cm. During the measurements, participants wore light clothing and were barefoot.

Bioimpedance analysis

Body composition parameters, including body fat, skeletal muscle mass, total body water (TBW), extra cellular water rate (ECW), and PhA, were measured using a multi-tactile impedancemeter with eight electrodes operating at a frequency of 50 kHz (InBody S10, Biospace, Seoul, Korea). The InBody S10 has been validated as an accurate method for estimating skeletal muscle mass in young individuals when compared to dual-energy X-ray absorptiometry, considered the gold standard (Malavolti et al., 2003). The bioimpedance analysis was performed with participants in a supine position. Prior to the test, participants were instructed to avoid exercise, diuretics, and caffeine for 12 hours, and to refrain from eating or drinking 30 minutes before the measurements.

During the procedure, the participants' skin was cleaned with alcohol, and the touch-type electrodes were placed on the thumb and middle fingers of both hands, as well as between the anklebone and heel of both feet. Participants remained in a supine position for 10 to 15 minutes prior to the test to ensure proper distribution of body water. Their arms were positioned away from the trunk at a 15-degree angle, and their legs were spread shoulder-width apart to prevent contact between the thighs. The measurements were conducted in the morning, in a room where the ambient temperature and relative humidity were controlled at 22-23°C and 50-60%, respectively. PhA was calculated as the ratio of electrical reactance to electrical resistance, using the following equation (Barbosa-Silva, Barros, 2005):

$$\text{PhA} = \text{arctangent}\left(\frac{\text{Xc}}{\text{R}}\right) \times 180°/\pi$$

Lower limbs strength

The standing long jump (SLJ) test was performed to evaluate the muscular power and strength of the lower limbs. Participants positioned both feet behind a designated line and jumped forward as far as they could, landing on both feet. The distance from the starting line to the nearest heel was measured using a tape measure. Each participant was given two attempts, with the longest jump being recorded for analysis.

Upper limbs strength

Upper body muscle strength was assessed using a handheld dynamometer to measure handgrip strength. A trained evaluator conducted the test with the Crown® 100 kgf / 1 kgf dynamometer. Participants performed the test while at rest in a standing position, with arms extended at their sides and forearms and wrists in a neutral position. They were instructed to execute three maximal isometric contractions, with a 30-second pause between each attempt. The test was conducted on both dominant and non-dominant hands, with three measurements taken for each. The average of the three measurements for each hand was recorded and expressed in kilograms/force (Fernandes, Marins, 2011).

Race characteristics

2400The race took place in Piripiri, Piauí, Brazil, on November 19, 2023, covered a distance of 75 km and was classified as Cross Country Marathon event, valid for the 8th state championship. Only athletes who were duly registered with the federation in 2023 were allowed to participate. The race had a maximum time limit of 5 (five) hours for all athletes to complete it. The results were recorded using an electronic chip timing system. At the start of the race at 8:00 AM, the temperature was 29.5°C, the relative humidity was 63%, and the wind speed was 1.6 km/h. By the end of the race, the temperature had risen to 36°C, the humidity dropped to 42%, and the wind speed was 1.3 km/h. The meteorological conditions during the race day were obtained from the website www.wunderground.com.

Statistical analysis

Data were presented as mean and standard deviation of the mean. Data normality and homogeneity were checked using the Shapiro-Wilk and Levene tests, respectively. Pearson's correlation was used to assess the relationship between independent and dependent variables. The strength of the correlations was classified using the following thresholds: < 0.3 negligible, >0.3 to 0.5 weak, >0.5 to 0.7 moderate, >0.7 to 0.9 strong, >0.9 very strong, and 1 perfect (Mukaka, 2012). For all statistical analyses, significance was accepted at $p < 0.05$. Data were analyzed using Graphpad Prism 9.0 (Graphpad Software Inc., San Diego CA, USA).

RESULTS

Table 1 presents the participants' characteristics, including body composition metrics (such as body mass, BMI, waist circumference, body fat percentage, skeletal muscle mass, and PhA) as well as performance indicators (handgrip strength, standing long jump distance and race time).

Table 1 - Description of body composition, phase angle and physical performance parameters of the participants.

Variable (n=83)	Mean ± standard deviation
Age (y)	39.6 ± 11.5
Body weight (kg)	77.1 ± 15.8
Height (m)	1.70 ± 0.08
Body mass index (kg/m^2)	26.5 ± 4.3
Waist circumference (cm)	86.3 ± 10.3
Body fat (%)	24.2 ± 7.8
Skeletal muscle mass (kg)	32.5 ± 6.1
Phase angle (º)	6.36 ± 0.7
Handgrip strength dominant (kgf)	41.5 ± 8.9
Handgrip strength nondominant (kgf)	39.3 ± 9.1
Standing long jump (m)	1.58 ± 0.3
Race time (min)	168 ± 30.3

The correlation between body composition parameters and physical performance variables are presented in Table 2.

Concomitantly, Figure 2 shows a significant correlation between PhA and physical performance parameters ($p<0.001$).

Table 2 - Correlation between body composition parameters and performance variables.

Variable	Handgrip(DH)	Handgrip (NDH)	Standing long jump	Race time
Body fat (%)	-0.289*	-0.353*	-0.601*	0.415*
Skeletal muscle mass (kg)	0.709*	0.665*	0.347*	-0.427*
Total body water (L)	0.690*	0.635*	0.314*	-0.400*
Extracellular water rate (units)	-0.363*	-0.519*	-0.569*	0.422*

Legends: DH, dominant hand; NDH, nondominant hand; *, Statistical significance.

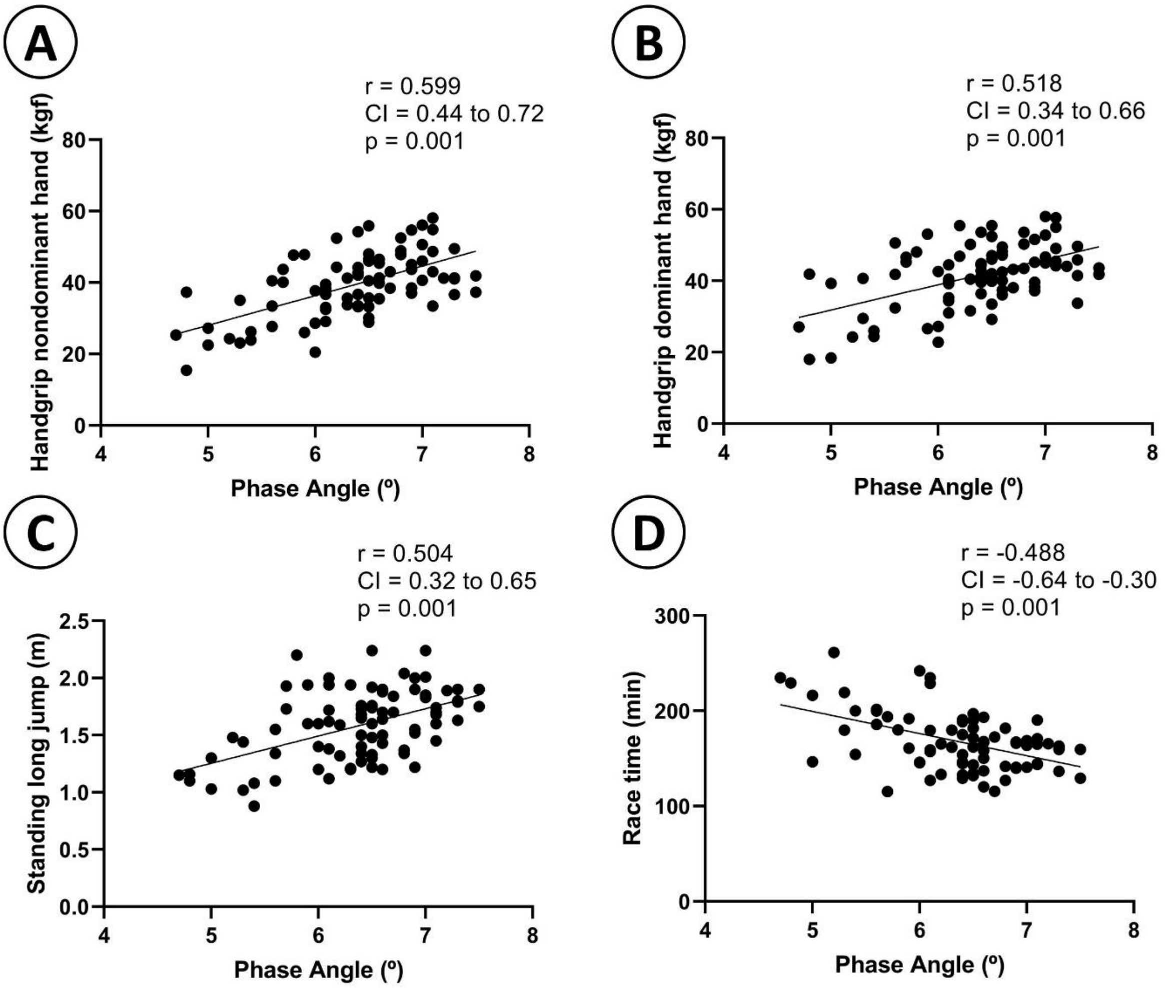

Figure 2 - Correlation between phase angle and strength and performance indicators in mountain bike athletes.
Legends: CI, 95% confidence interval.

DISCUSSION

The results of this study provide clear evidence that the PhA, obtained through bioimpedance analysis, is significantly correlated with maximal strength and performance in mountain bike athletes.

The positive correlations observed between PhA and handgrip strength, both in the dominant and non-dominant hands, suggest that PhA may reflect muscle integrity and contractile capacity, key characteristics for maximal strength performance. These findings align with previous studies that have identified PhA as a potential marker of muscle quality across various populations, including high-performance athletes.

Secondarily, we observed that body fat, skeletal muscle mass, total body water and extracellular water were also significantly correlated with upper body and lower body strength, as well as MBT performance.

PhA has been interpreted as an indicator of cellular integrity and the distribution of intra- and extracellular fluids, factors that are crucial for muscle performance (Akamatsu et al., 2022).

In the present study, the significant association between PhA and performance in the standing long jump, which is a lower limb strength test, supports this interpretation.

Indeed, studies indicated that higher lower limb PhA may be linked to improved vertical jump performance in elite soccer (Bongiovanni et al., 2021), handball (Silvino, Barros, et al., 2024), and badminton (dos Santos et al., 2021) players.

Additionally, a recent review showed that most of the studies presented a positive correlation between PhA and vertical jump (Cirillo et al., 2023).

Athletes with higher PhA values, indicative of greater cellular integrity and electrolyte balance, showed better performance in the power test, suggesting that PhA can be used as an indirect marker of muscle power.

The correlation between PhA and upper limb strength, as demonstrated by the positive associations with handgrip strength in both the dominant and non-dominant hands, highlights PhA's potential as a biomarker for muscle quality and cellular integrity in mountain bike athletes.

These findings are consistent with previous studies that have identified PhA as a predictor of strength and functional performance in athletes, particularly in sports that require upper body engagement (Cirillo et al., 2023; Matias et al., 2021; Yamada et al., 2022).

This underscores the relevance of PhA not only in evaluating body composition but also as a valuable marker of muscular strength and functional capacity.

The negative correlation between PhA and race time is also noteworthy. Athletes with higher PhA values tend to complete races in less time, suggesting that PhA not only reflects muscle strength but may also be related to metabolic efficiency and endurance.

A possible explanation for this finding is that a higher PhA may be associated with a lower content of extracellular fluids, indicating reduced inflammation and better muscle condition, which would contribute to improved efficiency during endurance activities.

In this sense, further studies investigating the relationship between PhA and aerobic capacity are suggested. A higher PhA indicates better fluid balance and membrane integrity, which can enhance oxygen utilization and delay fatigue, thus improving aerobic performance (Silvino, Batista, et al., 2024).

These findings align with previous studies that have linked higher PhA values to enhanced endurance, such as research by Yamada et al., (2022). Which demonstrated that older individuals with higher PhA exhibited better aerobic capacity and lower perceived exertion during endurance activities. In this context, PhA demonstrates a clear positive correlation with cardiovascular fitness across various age groups (Custódio Martins et al., 2022).

Therefore, PhA's role as an indicator of cellular integrity may translate into improved energy efficiency and endurance performance, making it a useful marker for assessing aerobic fitness in mountain bike athletes.

Although previous studies have investigated PhA in health and disease (Alves et al., 2022; Garlini et al., 2019) and sports (Santos et al., 2021; Nabuco et al., 2019; Silvino, Barros, et al., 2024) contexts, few studies have explored its application in mountain biking.

Comparing our findings with the existing literature, it is evident that PhA has consistently been associated with better muscle conditions in athletes.

However, our study is among the first to demonstrate its direct relevance to performance in this specific sport. This contribution is valuable as it suggests that PhA may serve as a useful tool not only for assessing muscle health but also for optimizing training and monitoring performance in endurance sports, including MTB.

Secondarily, the findings of this study reveal significant correlations between body composition variables and performance parameters in mountain bike athletes.

A noteworthy inverse correlation was observed between body fat percentage and physical performance variables, particularly in the standing long jump and race time.

These results suggest that higher body fat percentages may negatively impact both explosive strength and overall endurance performance, which are critical for competitive mountain biking.

The inverse relationship with race time aligns with previous research (Maciejczyk et al., 2014), indicating that excess body fat may increase energy expenditure during races, reducing overall efficiency.

However, in contrast to our results, a study found no significant correlation between body fat and aerobic performance in MTB athletes (Arriel et al., 2020). Thus, lower body fat may contribute to better performance by enhancing power-to-weight ratio and endurance capacity in athletes.

Additionally, skeletal muscle mass showed strong positive correlations with both handgrip strength in the dominant hand and nondominant hand, as well as a significant but weaker correlation with standing long jump.

This highlights the role of muscularity in strength and explosive power performance. The negative correlation between skeletal muscle mass and race time further supports the idea that greater muscle mass may enhance endurance and reduce fatigue during prolonged physical activity. In this context, it has been observed that fat-free mass is moderately related with aerobic capacity in MTB athletes (Arriel et al., 2020).

These findings highlight the importance of optimizing body composition, particularly by increasing skeletal muscle mass, to improve both strength-related and endurance aspects of performance in mountain biking athletes.

Finally, both total body water and extracellular water rate were also significantly correlated with upper limbs and lower limbs strength, as well as race time.

This information provides valuable insights into the physiological role of water distribution in athletic performance. TBW is crucial for maintaining muscle function, as water is essential for nutrient transport, waste removal, and maintaining electrolyte balance during exercise, especially in hot environments (Périard et al., 2016).

A higher TBW may indicate better hydration and muscle function, which can enhance contractile strength, particularly in the upper and lower limbs, leading to improved performance (Cheuvront, Kenefick, 2014).

Indeed, it has been stated that a body mass loss exceeding 2% is linked to a reduction in exercise performance (Engell et al., 1987).

Conversely, the ECW rate, which represents the proportion of fluid outside cells, is typically associated with inflammation and poorer muscle health (Yamada et al., 2017).

Our findings align with studies suggesting that optimal fluid distribution and cell membrane integrity, reflected by parameters like TBW and ECW, are key for maintaining strength and performance (Lorenzo et al., 2019; Serra-Prat et al., 2019).

The results of this study have important practical implications for coaches and athletes. PhA measurement can be integrated into routine assessments to monitor athletes' muscle condition and adjust training programs in a personalized manner.

Additionally, PhA may serve as an early indicator of fatigue or overload, enabling quicker interventions to prevent injuries. Future studies could explore the application of PhA in other sports and investigate interventions that might optimize PhA, such as nutritional strategies or recovery techniques.

Despite its significant contributions, this study has some limitations that should be considered. The cross-sectional design prevents determining causality between PhA and performance.

Additionally, skeletal muscle mass, body fat, total body water and extracellular water rate can also be used as indicators of physical performance in MTB athletes. Future longitudinal studies with more diverse samples are needed to confirm our results and further explore the potential of PhA as a performance marker across different sports contexts.

CONCLUSÃO

In conclusion, the findings of this study indicate that the phase angle, obtained through bioimpedance analysis, is significantly associated with maximal strength, muscle power, and performance in mountain bike athletes.

Secondarily, body composition parameters including skeletal muscle mass, body fat, total body water and extracellular water ration impact the physical performance in mountain bikers.

The correlations observed suggest that these variables may be useful markers for assessing muscle quality and metabolic efficiency in high-performance contexts, offering a non-invasive and accessible approach to optimize performance and prevent muscle overload in mountain bike athletes.

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