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ORIGINAL ARTICLE

Muscle oxygenation is associated with bilateral strength asymmetry during isokinetic testing in sport teams

L'oxygénation musculaire est associée à une asymétrie de force bilatérale lors des tests isocinétiques dans les équipes sportives

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Oxygen consumption;
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Skeletal Muscles;
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Sport medicine

Summary
Objectives. — Muscle oxygenation capacity is a metabolic component that can influence the bilateral strength asymmetry. This study measured the muscle oxygen saturation (SmO_2) during a protocol of high-intensity isokinetic fatigue (FAT) and its relationship with the body composition (BD) at the local level of the vastus lateralis.
Methods. — Twenty-two rugby players (age 22.5 ± 4.6 years, weight 89.8 ± 12.6 kg, height 176.4 ± 7.8 cm) performed a FAT test to obtain the peak moments (PM) torque of the knee muscle flexors and extensors. SmO_2 dynamics was evaluated using a portable NIRS, where muscle oxygen consumption, critical oxygenation, muscle oxygen extraction and recovery curves were obtained. The localized thigh BD was evaluated with dual-energy absorptiometry (DEXA). The tests were evaluated by dominant leg (DL) and non-dominant leg (not DL).

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Results. — Greater average peak torque were found in the DL of the knee extensor muscles (DL: 157 ± 28 vs. NDL: 148 ± 25; $P = 0.028$). Similarly, a SmO_2 difference (DL: 11.7 ± 10.1 vs. NDL: 16.3 ± 13.2; $P = 0.044$) and critical oxygenation (DL: 20.8 ± 10.1 vs. NDL: 26.3 ± 12; $P = 0.049$) is associated with greater bilateral strength asymmetry ($r = 0.618$ $P = 0.01$ and $r = 0.447$ $P = 0.03$). Also, a greater muscle mass showed an association with a better muscle oxygen extraction.
Conclusions. — This study highlights the use of SmO_2 dynamics as a complement to isokinetic tests in order to identify muscle metabolism and muscle imbalances in team sports such as rugby.

MOTS CLÉS
Consommation d'oxygène ;
Oxygénation critique ;
Muscles ;
Test d'effort ;
Médecine du sport

Résumé
Objectifs. — La capacité d'oxygénation musculaire est une composante métabolique qui peut influencer l'asymétrie de force bilatérale. Cette étude a mesuré la saturation musculaire en oxygène (SmO_2) au cours d'un protocole de fatigue isocinétique de haute intensité (FAT) et sa relation avec la composition corporelle (BD) au niveau local du vaste latéral.
Méthodes. — Vingt-deux joueurs de rugby (âge 22,5 ± 4,6 ans, poids 89,8 ± 12,6 kg, taille 176,4 ± 7,8 cm) ont effectué un test FAT pour obtenir le couple de moments de pointe (PM) des fléchisseurs et extenseurs des muscles du genou. La dynamique SmO_2 a été évaluée à l'aide d'un NIRS portable, où la consommation d'oxygène musculaire, l'oxygénation critique, l'extraction d'oxygène musculaire et les courbes de récupération ont été obtenues. Le BD localisé de la cuisse a été évalué par absorptiomètre à double énergie (DEXA). Les tests ont été évalués par jambe dominante (DL) et jambe non dominante (non DL).
Résultats. — Un pic de couple moyen supérieur a été trouvé dans la DL des muscles extenseurs du genou (DL : 157 ± 28 vs NDL : 148 ± 25 ; $p = 0{,}028$). De même, une différence SmO_2 (DL : 11,7 ± 10,1 vs NDL : 16,3 ± 13,2 ; $p = 0{,}044$) et une oxygénation critique (DL : 20,8 ± 10,1 vs NDL : 26,3 ± 12 ; $p = 0{,}049$) est associée à une plus grande asymétrie de force bilatérale ($r = 0{,}618$ $p = 0{,}01$ et $r = 0{,}447$ $p = 0{,}03$). De plus, une plus grande masse musculaire a montré une association avec une meilleure extraction d'oxygène musculaire.
Conclusions. — Cette étude met en évidence l'utilisation de la dynamique SmO_2 en complément des tests isocinétiques afin d'identifier le métabolisme musculaire et les déséquilibres musculaires dans les sports collectifs comme le rugby.

1. Introduction

Recently, studies with isokinetic dynamometry represent a generalized method for the evaluation of muscle performance in athletes, which is conditioned to fatigue during exercise [1]. Particularly, the temporary changes in the peak moments (PM) torque between the dominant leg (DL) and the non-dominant leg (Non-DL) and ratios between extensor and flexor knee muscles ''hamstrings and quadriceps'' are observed because they help to explain the risk of knee injury in sports [2,3], scientific literature has focused on isokinetic tests in athletes of soccer and rugby and has been successful in the prevention of new or recurrent lesion in these populations [4,5].

On the other hand, noninvasive near-infrared spectroscopy (NIRS) technology is used in portable instruments that are easily accessible to the sports population and scientifically validated with other NIRS of more economic cost [6]. These instruments use muscle oxygen saturation (SmO_2), which is the ratio of oxygenated haemoglobin with deoxygenated haemoglobin based on percentages of 1—100%. It is a relatively new parameter used by sports scientists [7] and, to date, SmO_2 has been studied with a performance approach making comparisons with VO_2max [8] and inverse relationships with heart rate (HR) during incremental exercise [9]. Likewise, the muscle oxygenation values evaluated with NIRS are influenced by the skinfold and the muscle mass involved in the muscle, presenting better oxygenation capacities in athletes compared to non-athletes [10]. It is also possible to evaluate the size and amount of localised muscle with the dual-energy X-ray absorptiometry (DEXA) method, being able to influence muscle oxygenation during exercise, since it has been observed that a greater amount of fat and adipocytes in the muscle indirectly affects oxygen supply by vasoconstrictor action and endothelial dysfunction [11]. Once the context of the study with wearable technology portable NIRS were observed, SmO_2 can be determined as a promising physiological marker to assess the oxidative performance of skeletal muscle during high-intensity exercise, where an intolerable workload can be identified due to the power-duration relationship known as critical power (CP) where the energy supply through phosphorylation at the substrate level reaches a stable state [12] and is measurable with the critical oxygenation (CO) and the muscle oxygen extraction reserve (MOE reserve) [13].

A recently published study [14], demonstrated that the muscle torque complexity behaves inversely with the metabolic rate during high-intensity contractions,

presenting lower SmO_2 values due to the central and peripheral fatigue. Although it is clear that the decrease in SmO_2 is a better predictor of performance during high-intensity tests, and is justified in strength training since better oxygenation improves power [9,10], no study has measured bilateral asymmetry with the SmO_2 dynamics: CO, MOE and recovery time during isokinetic fatigue test. In addition, we added localized muscle measurements as a possible factor of influence in the strength tests and SmO_2 dynamics. This study justifies the advancement of knowledge in performance and injury prevention by evaluating the possible bilateral deficit between the legs and the critical muscle oxygenation balance. Therefore, it is hypothesized that incorporating the SmO_2 measurement could help athletes monitor complement performance in isokinetic assessment. The objective of this study was to assess the SmO_2 dynamics during a high-intensity isokinetic fatigue protocol and its relationship with the bilateral strength asymmetry and body composition variables at the local level of the vastus lateralis muscle.

2. Methods

2.1. Participants

This cross-sectional study was conducted in a convenience sample composed by twenty-two male players (age 22.5 ± 4.6 years, weight 89.8 ± 12.6 kg, height 176.4 ± 7.8 cm, sports participation 9.1 ± 3.6 years) from the rugby Portuguese first division. All participants were healthy and met the following inclusion criteria: (1) between 18—35 years of age; (2) playing rugby for at least 5 years as an professional player; (3) absence of any lower limb injuries within the last three months; (4) no past severe injury that may affect their lower limbs, and; (5) no use of substances that enhance the acute effect of exercise. All participants signed an informed consent. To avoid any residual fatigue induced by recent training, participants were asked to refrain from strenuous exercise 48 hours before the tests. This research protocol was approved by the Scientific and Ethical Committee of the University of Extremadura with Number of registration: 131/2018 and it was in accordance with the principles of the Declaration of Helsinki.

2.2. Protocol

Initially, the club's coaching staff was contacted and participants attended a pre-study briefing. Data collection was carried out during the pre-season. A self-reported questionnaire was applied to collect information on sociodemographic characteristics, beverage intake, dietary habits, medical history, and oral hygiene habits. Then, body composition measurements were performed using a dual-energy X-ray absorptiometry (DEXA) in the morning hours (6:00 am—9:00 am), following manufacturers' recommendation [15]. Finally, each player performed the high-intensity isokinetic fatigue test (FAT). The laboratory was air-conditioned, and the room temperature was maintained between 22 and 24 °C.

2.2.1. High-intensity isokinetic fatigue test (FAT)

The test was performed on a Biodex System-3 Isokinetic Dynamometer (Biodex, System 3, NY, USA), which consisted of a 5-minute warm-up by pedaling at 100 watts with a cadence between 90 and 100 rpm on a cyclo-ergometer (ergometrics 900, ergoline Germany). Thereafter, the subject was seated on the dynamometer seat with his back reclined at 85 and stabilized using thigh, pelvic and shoulder straps. The mechanical axis of the dynamometer was aligned with the knee's axis of rotation, with the lateral femoral condyle used as the landmark. The resistance pad was adjusted to face a point 3 cm above the lateral malleolus. The test was performed on the dominant leg (DL) and non-dominant leg (Non-DL), defined as the preferred kicking leg. The order of testing was randomized for the dominant and non-dominant legs. The weight of the leg was recorded and gravity adjustment was made using the dynamometer software.

The range of motion was 100° (0° corresponding to a full active extension). Familiarization with the dynamometer and the set-up included ten submaximal and progressively intensified concentric contractions (extension and flexion) at an angular velocity of 120°/s. After a 2 min pause, the subjects were he is asked to perform 3 submaximal reciprocal concentric contractions at an angular velocity of 180°/s. Subsequently they performed 30 consecutive maximal reciprocals concentric contractions at an angular speed of 180°/s. Is velocity was chosen because low angular velocities, such as 60°/s induces greater torque development and increases the duration of each contraction. Such conditions may involve, through repeated contractions, progressive discomfort possibly leading lack of motivation and increased risk of injury. Strong verbal encouragements were given throughout the test to motivate participants to develop maximal torque during each repetition, as mentioned in the study by McNair et al. [16].

The work performed during the entire range of motion of each repetition was computed using the device's software and summed to obtain the FAT total work (N.M). We previously showed that this measure was very highly reliable for knee extensors (ICC = 0.91) and highly reliable for knee flexors (ICC = 0.75) [17]. In addition values of the peak moments (PM) torque were obtained for maximum and average, were taken in N.M.

2.2.2. NIRS measurement

The measurements were made with the NIRS portable sensor (MOXY, Fortiori Design LLC, Minnesota, USA). It is valid for measuring SmO_2 during exercise (ICC: $r = 0.773$—0.992, $P \leq 0.01$) [9]. NIRS sensor was placed in the vastus lateralis, between the greater trochanter and the lateral femoral epicondyle. MOXY data was recorded constantly throughout the test. Data were recorded in real time (visible only to researchers) using the Matlab® software (The MathWorks, Inc., Massachusetts, United States) and ANT + technology (GoldenCheetah).

2.2.3. SmO_2 dynamics analysis

The study variables of SmO_2 have been proposed according to the rate of consumption and recovery of muscle oxygenation [13,18,19]: (a) SmO_2 Start after warm-up; (b)

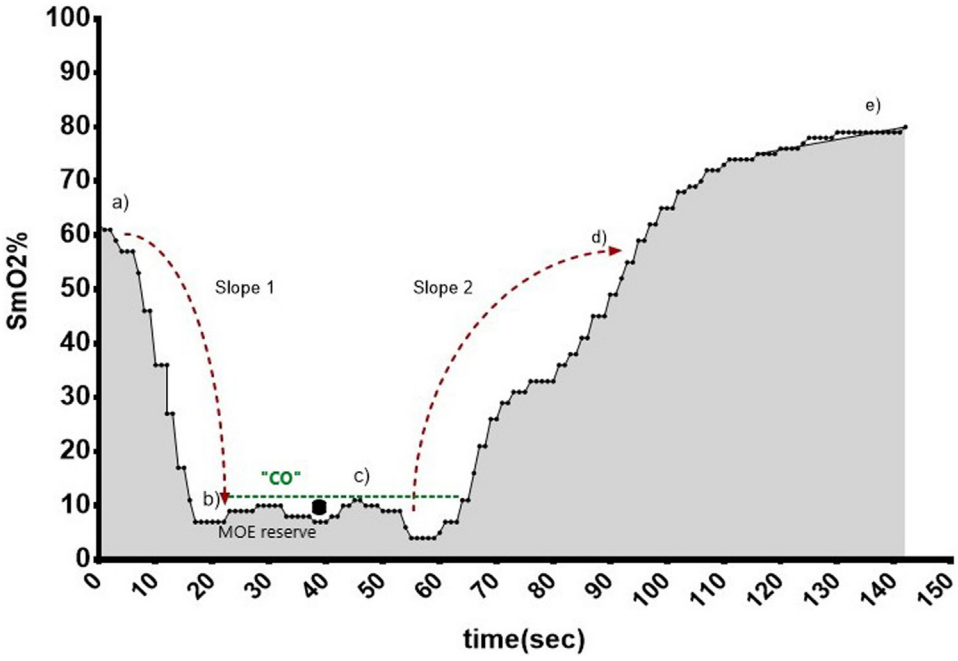

Figure 1 Diagram of variables studied in the SmO_2 dynamics. Where: (a) = start of exercise; (b) = minimum SmO_2 and muscle oxygen extraction reserve ''black point''; (c) = critical oxygenation ''green line''; (d) = SmO_2 recovery baseline and (e) = SmO_2 recovery until stabilization. The ''SmO_2 Slope 1'' is the difference between point (a) to point (b) and the ''SmO_2 Slope 2'' is the difference between point (c) to point (d) ''red line''.

minimum SmO_2 during the test and muscle oxygen extraction reserve; (c) Critical Oxygenation (stabilized SmO_2 during the test); (d) SmO_2 Recovery time to baseline (s); and (e) SmO_2 Recovery $\leq$ 3 min. During the recovery phase, the participants remained seated in the isokinetic seat until the peak value of SmO_2 was maintained. In addition the following are proposed: muscle oxygen consumption rate (SmO_2 Slope 1) and muscle oxygenation during recovery as an estimate of the oxidative capacity of muscle, since it is similar to recovery phosphocreatine (PCr) (SmO_2 Slope 2) [20], as it is shown in the diagram study variables of SmO_2 (Fig. 1).

The percentage of lower limb asymmetry was calculated with the equation of standardized absolute asymmetry score (AA):

$$AA = \left(\left|R - L\right|\right) / (1/2\,(R + L)) \times 100\%$$

where L = left measurement and R = right measurement. This measure that does not take into account the directionality of the asymmetry [21].

2.2.4. Body composition

Variables such as percentage fat mass (CV = 2.1%) and percentage lean mass (CV = 1.7%) of thigh muscle were obtained using dual-energy X-ray absorptiometry (DEXA, Norland Excell Plus; Norland Inc., Fort Atkinson, United States). Before the DXA scan, participants were asked to removeall metal objects and to change into a gown. Scanning was performed with the subject supine, and the scan time was within 15 min. Thigh fat and lean mass were analysed by one technician and determined by redefining the region of interest using the body composition analysis software. Lines through the femoral neck parallel to and just proximal to the greater trochanter and through the knee joint line, respectively, defined the superior and inferior borders of the region of interest [22]. The same experienced technician performed all the scans, which were analysed by a graphical user interface (GUI) to Windows XP operating system.

2.3. Statistical analysis

Initially, the Shapiro—Wilk normality test was used to assess data normality. A Student *t*-test was performed for related samples (comparison between DL and NoDL). The magnitude of the difference was assessed by the Hedges g (g), as presented elsewhere [23]. The magnitude of the difference was considered either small (0.2 < g″ 0.5), moderate (0.5 < g″ 0.8), or large (g > 0.8). Relationships between imbalances asymmetry of extensor and flexor of knee strength and SmO_2 variables were analysed using Pearson's product-moment correlation. Correlations were evaluated using Hopkins' scale [24] and interpreted as follows: trivial (0.00—0.09), small (0.10—0.29), moderate (0.30—0.49), large (0.50—0.69), very large (0.70—0.89), nearly perfect (0.90—0.99), and perfect (1.00). All statistical analyses were performed using the SPSS version 22.0 for Windows (IBM® SPSS® Statistics 22). The statistical significance level was set at $P < 0.05$.

3. Results

Table 1 shows that there was a higher PM maximum and medium in knee extension in DL compared to Non-DL, with a

Table 1 Comparison of peak torque and thigh composition (DEXA) between dominant leg vs. non-dominant leg during high-intensity isokinetic fatigue test.

Isokinetic test	Dominant leg	Non-dominant leg	Bilateral asymmetry (%)	Hedges (g)	*P*-value
Knee extension					
Peak torque max (N.m)	210 ± 37	201 ± 32	4	0.256	**0.043**
Peak torque med (N.m)	157 ± 28	148 ± 25	6	0.333	**0.028**
Total work (N.m)	−3.32 ± 1.32	−3.02 ± 1.49	9	0.209	0.147
Knee flexors					
Peak torque max (N.m)	58 ± 19	54 ± 10	7	0.259	0.188
Peak torque med (N.m)	82 ± 12	81 ± 14	1	0.075	0.869
Total work (N.m)	−1.56 ± 0.73	−1.54 ± 0.82	1	0.025	0.896
Thigh muscle composition (DEXA)					
Fat (grams)	2421 ± 96	2451 ± 100	1	0.030	0.490
Fat (%)	2194 ± 56	2216 ± 58	1	0.103	0.609
Muscle mass (grams)	8263 ± 90	8247 ± 96	0	0.021	0.859
Total mass (grams)	10,682 ± 171	10,693 ± 177	0	0.006	0.896

*P-value < 0.05 and **P-value < 0.01 statistically significant. Values are expressed as mean ± standard deviation.

Table 2 Comparison of SmO_2 between dominant leg vs. non-dominant leg during high-intensity isokinetic fatigue test.

SmO_2 dynamics	Dominant leg	Non-dominant leg	Bilateral asymmetry (%)	Hedges (g)	*P*-value
SmO_2 start	62.1 ± 11.4	62.4 ± 11.2	0	0.000	0,915
SmO_2 minimum during the test	11.7 ± 10.1	16.3 ± 13.2	**39***	0.384	**0.044**
SmO_2 minimum time (s)	27 ± 7	26 ± 7	4	0.140	0.776
Critical oxygenation of SmO_2	20.8 ± 10.1	26.3 ± 12.2	**26***	0.482	**0.049**
SmO_2 maximum time (s)	34 ± 8	35 ± 6	3	0.151	0.657
SmO_2 recovery	79.3 ± 5.7	74.3 ± 14.9	6	0.435	0.101
SmO_2 recovery time to baseline (s)	143 ± 13	136 ± 19	5	0.422	0.121
Muscle oxygenation reserve	6.28 ± 4.6	6.76 ± 4.1	25	0.110	0.686
SmO_2 medium	21.1 ± 13.8	26.6 ± 15.1	26	0.422	0.095
SmO_2 Slope 1	49.5 ± 14.9	44.2 ± 13.8	11	0.362	0.238
SmO_2 Slope 2	55.3 ± 15.8	55.9 ± 16.4	1	0.040	0.672

**P-value < 0.01 statistically significant. Values are expressed as mean ± standard deviation.
* P-value statistically significant.

bilateral asymmetry of 4% and 6% respectively. No difference was observed in the rest of the variables.

Table 2 shows a greater decrease in SmO_2 was found in DL less than the Non-DL leg, with a bilateral asymmetry of 39%. Likewise, the DL reached lower values in the CO of SmO_2 during the test less than the Non-DL leg and a bilateral asymmetry of 26%. No statistically significant differences were observed in the other variables.

Table 3 shows the Pearson value (r) between SmO_2 with peak torque variables and thigh composition. It was found that the faster the time it takes to reach the minimum of SmO_2, the greater the force in knee extension PM maximum and medium. In the work peak torque of knee flexors, an inverse relationship it is also observed with SmO_2 Slope 1, with a higher consumption of SmO_2 occurring when less force is made in the hamstrings.

Regarding the thigh muscle composition, a relationship between greater fat with higher values of critical oxygenation is observed. Also, the greater the muscle mass and total mass (g), the faster the use of SmO_2 and the greater muscle oxygen extraction reserve will be during the test. Although most of the correlations are effects moderate and large, this is an advance in understanding the process of testing using bilateral deficits through SmO_2.

4. Discussion

This is the first study showing a difference in the minimum SmO_2 and critical oxygenation between DL and Non-DL that could refer to a better performance in the DL [14,25]. In addition, this research provides an advance in the knowledge of how the muscle uses metabolic energy during an isokinetic test through of SmO_2 measurement. First, in reference to the results found for the difference in peak torque in knee extension coincides with the results of the study by Brown et al. [4] who found that rugby players have less strength in the Non-DL in extension and flexion, since it was limited to an angular force of 60°/s. Likewise, the 2010 Bosquet study used the same protocol, where it found values between 120 to 180 Nm in extension and 40 to 110 Nm in flexion in sedentary subjects [17], the values obtained in our study are of interest to rugby fitness coaches and future interpretations of the FAT test.

Table 3 Correlation of bilateral asymmetry between SmO_2 variables with peak moments torque and thigh composition (DEXA).

Variables relationship	Minimum SmO_2	SmO_2 minimum time (s)	Critical oxygenation of SmO_2	Critical oxygenation of SmO_2 time (s)	Muscle oxygen extraction reserve	SmO_2 recovery	SmO_2 recovery time (s)	SmO_2 Slope 1	SmO_2 Slope 2	SmO_2 (k)
Knee extension										
Peak torque max (N.m)	0.284	**0.603****	**0.447***	0.165	0.075	0.109	0.236	0.383	0.212	−0.054
Peak torque med (N.m)	0.245	**0.618****	0.232	0.020	0.249	0.352	0.171	0.237	0.295	0.125
Total work (N.m)	0.229	0.117	0.202	0.402	0.132	−0.075	0.435	0.138	−0.067	−0.185
Knee flexion										
Peak torque max (N.m)	0.145	−0.149	0.234	0.135	0.049	−0.144	−0.222	−0.138	−0.036	−**0.433***
Peak torque med (N.m)	0.064	−0.232	0.230	0.404	0.143	−0.246	−0.268	−**0.449***	−0.359	−**0.463***
Total work (N.m)	0.228	−0.131	0.238	0.091	−0.147	−0.353	−0.242	−**0.458***	−0.347	−**0.459***
Leg composition (DEXA)										
Fat (grams)	0.147	0.143	**0.425***	−0.149	0.067	−0.186	−0.117	−0.374	−0.255	0.050
Muscle mass (grams)	0.281	**0.460***	−0.367	0.219	**0.527***	0.016	−0.315	0.103	0.128	−0.193
Total mass (grams)	0.049	**0.530***	0.118	−0.205	**0.502***	0.109	−0.345	−0.141	−0.150	0.132

Statistics based on mechanical inference with the effect magnitude: trivial (0.00—0.09), small (0.10—0.29), *moderate (0.30—0.49), *large (0.50—0.69), **very large (0.70—0.89), ***nearly perfect (0.90—0.99), and ****perfect (1.00).

Regarding, the values obtained from maximum peak torque and average peak torque in the present study were associated with the decrease in SmO_2, this is similar to the study by Pethick et al. [14] where they obtained results of an inverse correlation in isokinetic tests and which is expressed in a greater bilateral strength asymmetry with SmO_2 and CO. Likewise, recent studies, SmO_2 has been a variable associated with energy expenditure, explained by the muscle oxidation capacity [20,26]. Starting from this hypothesis, it could be considered that the response of muscle performance by SmO_2 was determined by the requirement of the peak torque force and a high fatigue component during the test [27] this explains that once the call is reached critical power, where the intensity of the effort cannot be maintained [12], a smaller decrease in SmO_2 is observed and the beginning the CO increase, where the muscle needs the production of oxygen to maintain a greater set of motor units and the associated force [28], this is where the existence of the change of units recruited in type II fibers to a higher percentage of type I fibers and greater phosphorylation is presumed [13], according to Davies et al. [29], characterised by a slow process increase in SmO_2 and a decrease in intramuscular pressure (IPM) that promotes increased blood flow [30], however in this process the decrease in peak torque begins. This physiological mechanism was explained in the study by Vasquez-Bonilla [19] in which a non-linear relationship is observed between SmO_2 and power due to changes in muscle hemodynamics during high-intensity tests. Similar to our study, even the test was for a very short time, but we were able to observe when the athletes could not maintain the effort due to the high-intensity [27]. Following the context, this means that the CO in the Non-DL was caused by lower peak torque throughout the test. Although the cause of force differences is unknown, to date it is considered to be caused by an increase in ATP production or indicating a progressively higher ATP resynthesis from oxidative phosphorylation, is also associated with a progressively higher contribution to ATP resynthesis deriving from PCr splitting and anaerobic glycolysis, thereby suggesting an overall decreased efficiency of muscle contraction [28]. This decrease in efficiency is intrinsically associated with muscle fatigue and ultimately with exhaustion [28].

Regarding the thigh composition variables (DEXA), it has been observed that having greater muscle mass means that less SmO_2 and greater PCr is used, since muscle mass stores most of the PCr in the muscle fibres [31], ready for use during the exercise. A greater total mass and muscle mass has an affinity for a greater capacity for muscle oxygen extraction reserve [32]. Also, fat mass influences the increase in energy expenditure [33] showing an affinity for the SmO_2 increase and a lower capacity to resist CO [34]. However, the current study did not find differences between the legs in terms of muscle mass and fat mass located in the thigh, which could mean that oxygenation depends on other components at the systemic level [35,36] and on endogenous variables such as type and a greater number of muscle fibers [29] and exogenous such as the nutrition of athletes, since the oxidative metabolism of carbohydrates and lipids provides almost all the ATP necessary for contractile activity. Finally, this study provides a new advance in the interpretation of NIRS, since the SmO_2 has a different mechanism in anaerobic exercises compared to aerobic exercises, and this could explain why many studies do not find a difference in the anaerobic conditions [9]. Also, in the last studies of Bosquet in 2015 and 2016 [1,37], which interpret the FAT test to track the muscle performance of athletes, SmO_2 assessments could be added as a component of energy metabolism at the local level. It is important to recognise limitations of performing isokinetic evaluations, since it is often questioned because they are much slower than the extension/flexion speeds observed in real movements. A direct comparison with field tasks should be made to provide more accurate information on SmO_2 and carried out on the field of play, however, the isokinetic evaluation provides direct information on the strength of knee extensors and flexors.

As a suggestion, future studies of SmO_2 with isokinetic should differentiate the sample with the level of interindividual training of athletes. In addition, they should compare different times of the season, evaluating the recovery variable of SmO_2 since it is directly related to the yield on the use of PCr. Furthermore, a limitation of this protocol is that it does not measure the dynamic control ratio (DCR), which has valuable information on the risk of injury. It is also proposed to find standard values of bilateral strength asymmetries in SmO_2 because these are still unknown in the sports sciences.

5. Conclusions

It is concluded that the smallest difference in SmO_2 could directly affect a greater bilateral strength asymmetry. Furthermore, the ability to decrease muscle oxygenation the muscles does not depend directly on the fat mass and muscle mass at the local level of the muscle. However, athletes with greater muscle mass can use SmO_2 faster and achieve a greater muscle oxygen extraction reserve through the phosphocreatine energy substrate in the first few seconds of an anaerobic test, this causes a greater maintenance of maximal strength and power. Finally, we propose to measure of the SmO_2 as a complement to isokinetic performance and to advance research in the monitoring the metabolism and hemodynamic muscle in sports teams.

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Disclosure of interest

The authors declare that they have no competing interest.

Ethics approval

The study design was approved by the Bioethical and Biosecurity Commission of the University of Extremadura (document 138/2018).

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