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Effects of altitude on biceps brachii and erector spinae muscles oxygen saturation during basic cardiopulmonary resuscitation: a simulation study

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Abstract: **Objective:** To assess biceps brachii and erector spinae muscular oxygen saturation (SmO2) by near infrared spectroscopy (NIRS), during 10 minutes of resuscitation at simulated altitudes of 600, 3000 and 5000 m before and after carrying out a simulation program for adaptation to hypoxia. Performing and maintaining a good-quality cardiopulmonary resuscitation (CPR) at higher altitudes may pose a significant challenge to resuscitators due to decrease in arterial oxygen saturation. This fact adversely effects the quality of resuscitation.

Methods: Participants performed 10 minutes of CPR on a mannequin in the laboratory in environments that simulated altitudes. Subsequently, a standardized altitude conditioning protocol was carried out using intermittent hypoxia. The participants performed CPR again under the conditions and altitudes previously referred to.

Results: Initial heart rate (HR) at 5000 > 3000 m, and both > 600 m. HR at each altitude was higher conditioning at the end of CPR. The SmO2 of both muscles showed no differences at the beginning and at the end of CPR and was higher in both muscles after the conditioning program before and at the end of CPR. In both muscles, SmO2 values before and after conditioning show a slightly increasing trend during CPR.

Conclusion: NIRS use allows developing an optimum training plan. The rescuer will know his limits and optimize his performance. The improvement in physical performance and recovery capacity induced by intermittent hypoxia conditioning programs increases the quality of CPR in prolonged cardiac arrests and in adverse conditions, such as at high altitudes.

Keywords: Basic Cardiac Life Support; Heart Massage; High Altitude; Hypoxia; Near-Infrared Spectroscopy

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1. Introduction

Survival rates of out of hospital cardiac arrests (OHCA) is estimated to be below 10% (1). Good-quality cardiopulmonary resuscitation (CPR) maneuvers benefit survival after OHCA —by even doubling or tripling the survival rate (1,2). During CPR, chest compressions (CC) combined with breaths following strategy 30:2 are potentially effective in helping survival of people with OHCA (3). For this purpose, adult patients require CC between 5 and 6 centimeters (cm) deep, in 50:50-proportion compression-decompression cycles achieved through compressions exerted mid-sternum at a rate of 100 to 120 per minute (4). During CPR maneuvers, biceps brachii and erector spinae muscles play a significant role in the position and performance of CC (5).

It has been proven that in the general population and under ideal environmental conditions, the resuscitator's efforts during CPR are essentially aerobic and submaximal, and the cardiorespiratory system can tolerate these exercises well. The resuscitator's shape influences CPR quality as well as endurance until the arrival of help (6,7).

In recent years people have shown a considerably higher interest in outdoor activities at a high altitude, such as hiking, mountain climbing and skiing. Even the number of amateurs becoming fans of such disciplines has grown noticeably in the past years (8) —it is common to find sport teams exercising or supporters following sport events over medium and high altitudes. Staying and moving at a high altitude produces a variety of physiological effects, such as an increase in cardiac and respiratory workload, mainly during physical activity (9,10).

Performing and maintaining a good-quality CPR at higher altitudes may pose a significant challenge to resuscitators. Previous studies have demonstrated that after a 5-minute CPR at altitude, resuscitators' arterial oxygen saturation (SpO2) decreases and heart rate (HR) increases. This fact adversely influences CC and ultimately, CPR quality (11-16).

Endurance of the skeletal muscle relies on oxidative metabolism and thus on the amount of oxygen (O2) available. The percentage of O2 absorbed by muscular tissue during oxidative metabolism for generating power can be calculated through muscular oxygen saturation (SmO2) (17,18).

It is possible to estimate tissue oxygenation by near infrared spectroscopy (NIRS) (18). NIRS establishes SmO2 based on the relation between oxyhemoglobin and hemoglobin total values in blood and expresses it as a percentage (%SmO2) (19). NIRS is considered an excellent technique to evaluate performance during physical activity given the proportional relationship between %SmO2 and the ability to carry out physical activity (20,21).

NIRS has proved to show fatigue better than HR-based measurements (13). It has been demonstrated as well that correlation between NIRS and maximal lactate steady state is a valid sign of endurance and training (22,23).

NIRS devices connected to displays (computers, tablets, or watches) allow real-time measuring of SmO2 consumed by the body during physical activity, outdoors and in laboratory tests (24,25). In sports, this muscular-oxygenation-based measuring method has been employed as a predictor of endurance in disciplines such as climbing, race walking and cycling (26,27).

Normobaric intermittent hypoxia exposure (NIHE) occurs when breathing air with low O2 content under regular environmental pressure conditions, with the aim to stimulate hematological adjustments (increased production of erythropoietin, hemoglobin, erythrocytes) and changes in performance (modifications in pH regulation and lactate transport) which are typical of acclimation to altitude (28).

No previous studies have monitored the SmO2 of biceps brachii and erector spinae during CPR at different altitudes or studied the likely effect of a program for adaptation to hypoxia caused by altitude. Thus, our objectives were: a) to assess biceps brachii and erector spinae SmO2 during 10 minutes of CC at simulated altitudes of 600, 3000 and 5000 meters (m) after running a program for adaptation to hypoxia caused by altitude; b) to describe the effects of altitude training on biceps brachii and erector spinae SmO2 related to CPR at such altitudes.

2. Methods

2.1. Study design

An analytical before-after study in which participants, selected for convenience performed CC inside a laboratory for 10 minutes on a mannequin in environments simulating different altitudes (600, 3000 and 5000 m). It was hence followed by an intervention based on a standardized protocol for adaptation to altitude by inducing intermittent hypoxia. After acclimation to hypoxia, the same participants performed CC one more time under the same simulated conditions and altitudes.

2.2. Study population

10 people in their third or fourth year of bachelor's degree in nursing (5 women) with training in CPR in compliance with resuscitation guidelines ERC 2021 (ERCGR2021) were invited to participate (4) —all of them being of age and none suffering from any illness or physical disability preventing them to participate in the study.

Exclusion criteria were suffering from any chronic or acute condition, serious psychiatric disorder, tumor pathology, uncontrolled hypertension, serious imbalance problems, intolerance to hypoxia caused by the different simulated altitudes during CPR, inability to reach 85% of correction in CC in CPR at 600 m. Three participants were excluded as they did not comply with the last criterion.

2.3. Study process

Sociodemographic variables (sex, age, and level of education) as well as the weight and height of each participant was collected initially. All of them took the primary test on tolerance to hypoxia according to protocol iAltitude (29). The flowchart of the study is shown in figure 1.

- Test 1: All participants performed 10 minutes of uninterrupted CPR on the mannequin placed on the floor (CC to ventilation by bag-valve mask ratio=30:2) at simulated altitudes of 600, 3000 and 5000 m. Prior to CPR at each altitude, participants had a 10-minute period for adaptation to fraction of inspired oxygen (FiO2) as it was expected to be in each simulated environment. In between tests 60 minutes served for physical recovery.

■ NIHE physical conditioning: Following the initial measurements, an intervention was carried out alternating phases of hypoxia and normoxia according to the iAltitude conditioning program, with 967 minutes distributed in sessions of 56 -72 minutes, alternating cycles of hypoxia (FiO2 of 0.14 in the initial sessions to 0.11 in the final ones) and normoxia, resulting in 728 minutes of hypoxia total time.

- Test 2: Once the conditioning program for intermittent hypoxia was completed, all participants performed 10-minute continued CPR at simulated altitudes of 600, 3000 and 5000 m with a previous 10-minutes period for adaptation to FiO2 in accordance with the simulated altitude, and 60 minutes between tests for physical recovery.

Considering the advice by Bastida-Castillo et al. (30) about where to place the device to detect changes in oxygenation in muscular tissue, each participant had two Humon Hex® devices placed on their dominant body zones. One device for the biceps brachii, on the wider area of the arm, and the other for the erector spinae, placed at the center of the muscle. Each Humon Hex® was synchronized with an iPad®, Apple Inc. by switching on the corresponding application to check SmO2, amount of time of exercise and HR (25). SmO2

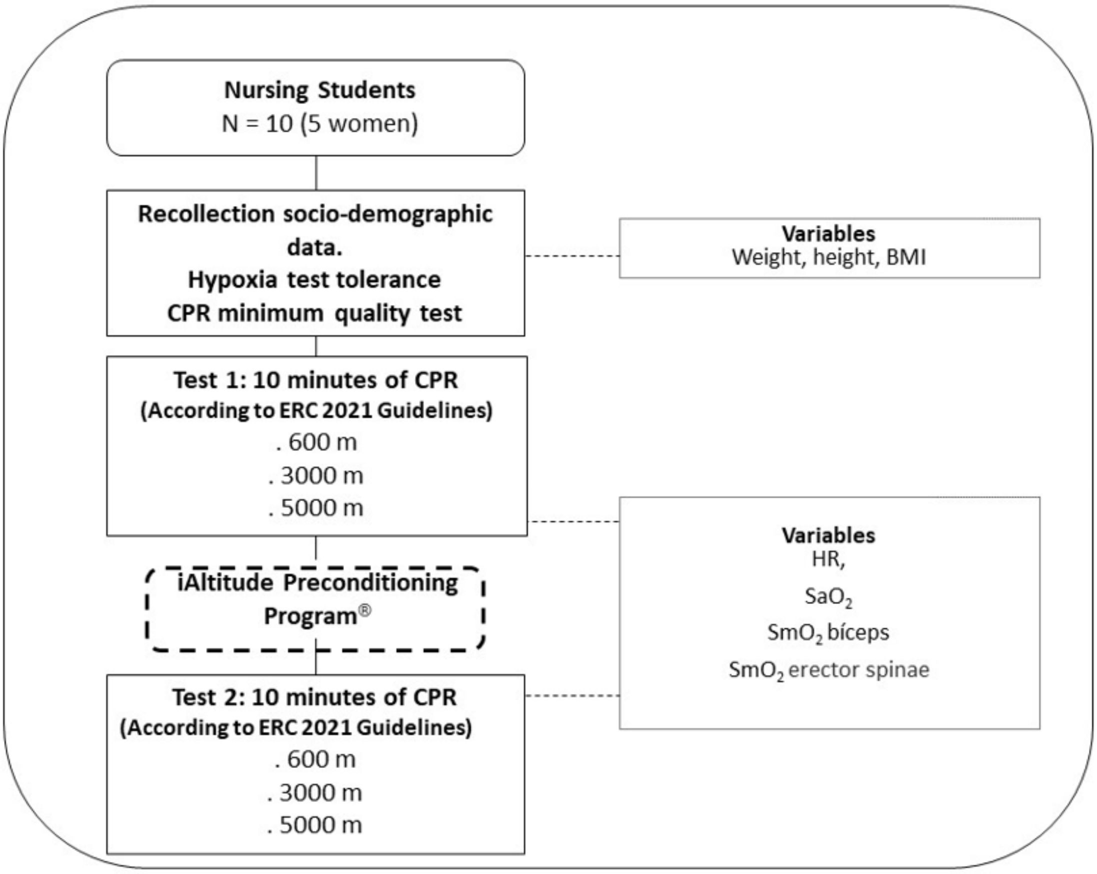


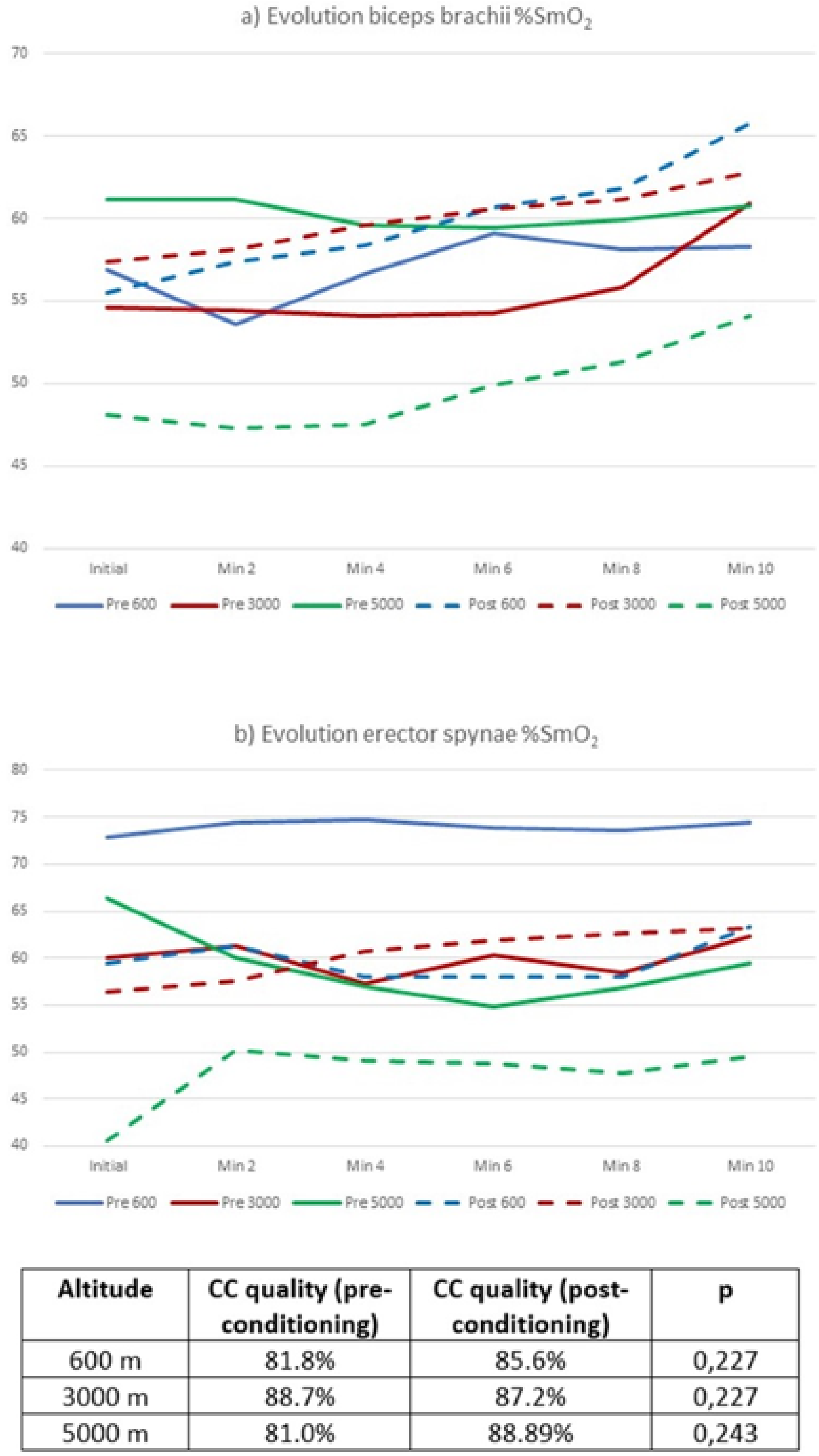
Figure 1 Study flow diagram

Table 1 Basic characteristics of the population

	Gender (Men 4, women 3)	Mean	SD	CV	t-value	P-value
Age, years	Men	23.3	4.4	18.26		
	Women	22.4	1.6	7.24	1.356	0.096
Weight, Kg	Men	80.64	11.36	14.09		
	Women	64.86	9.35	14.42	3.393	**0.002**
Height, cm	Men	174.2	7.63	4.35		
	Women	163.6	7.63	4.61	2.810	0.006
BMI, Kg/m^2	Men	21.1	2.66	10.16		
	Women	18.1	2.55	10.82	2.243	**<0.001**
HR, bpm	Men	82.8	14.4	18.02		
	Women	80	10.5	13.36	0.230	0.410
SBP, mmHg	Men	135.5	14.1	10.63		
	Women	123.0	15.3	12.44	1.875	0.390
DBP, mmHg	Men	77.7	10.0	12.87		
	Women	79.3	9.3	11.73	0.369	0.358
SpO2, %	Men	99.3	0.4	0.4		
	Women	99.0	0.8	0.81	0.000	0.500

BMI: Body mass index; HR: Heart rate; SBP: Systolic pressure; DBP: Diastolic pressure; SpO2: Partial oxygen saturation; bpm: Beats per minute; cm: Centimeter; kg: Kilogram; SD: Standard deviation; CV: Coefficient of variation
In bold type: P≤0.05

values were concluded from the SmO2/exercise time curves generated by Humon Hex®, from which data were also selected for subsequent phases: a) prior to exercise; b) drop phase: when SmO2 drops drastically (Humon Hex® indicates this fact with a change of color (orange); c) maximum drop coinciding with exercise maximum intensity and maximum peak or maximum oxygen uptake, (red color); and d) recovery phase: after the exercise, when values return to normal (indicated by another color change color on the graph from blue to green).



Altitude	CC quality (pre-conditioning)	CC quality (post-conditioning)	p
600 m	81.8%	85.6%	0,227
3000 m	88.7%	87.2%	0,227
5000 m	81.0%	88.89%	0,243

Figure 2 %SmO2 evolution during CPR; a) biceps brachii; b) erector spinae and quality of CC at different altitudes before and after conditioning

The CPR test was performed on an electronic mannequin designed for CPR education purposes (Laerdal Resusci Anne CPR-D and SkillRepoter®; Medical Laerdal; Stavanger, Norway) placed on the ground and configured according to the

Table 2 Comparison of mean values of HR, SmO2 (%) in biceps brachii and erector spinae during CPR at different altitudes before and after conditioning

			F-value	P-value
Pre-conditioning values	HR, bpm	Altitude	3.144	0.080
		Moments	23.198	**0.003**
	Biceps brachii SmO2, %	Altitude	0.268	0,769
		Moments	3.448	0.113
	Erector spinae SmO2, %	Altitude	2,138	0,180
		Moments	1.797	0.251

HR: Heart rate; SmO2: Muscle oxygen saturation; Moments: CPR initial, CPR final;
bpm: Beats per minute
In bold type P≤0.05 statistically significant

Table 3 Comparison of HR and SmO2 mean values (%) in biceps brachii and erector spinae during CPR at 600 m with those obtained at 3000 and 5000 m (preconditioning)

600 m variable	Moment	Mean value	Altitude	Moment	Mean value	t-value	P-value
HR, bpm	Initial	81.60	3000	Initial	90.5	0.579	0.584
	Final	169.1		Final	153.7	1.778	0.126
			5000	Initial	92.7	2.379	0.055
				Final	163.35	5.712	**0.001**
Biceps brachii SmO2, %	Initial	56.85	3000	Initial	54.59	0.452	0.667
	Final	58.28					
				Final	60.94	0.732	0.492
			5000	Initial	61.14	0.667	0.530
				Final	60.75	0.430	0.682
				Final	65.12	2.047	0.087
Erector spinae SmO2, %	Initial	72.79	3000	Initial	59.96	2.333	0.080
	Final	74.47	5000	Final	62.30	1.854	0.113
				Initial	66.34	1.675	0.169
				Final	65.12	2.047	0.087

HR: Heart rate; SmO2: Muscle oxygen saturation; bpm: Beats per minute
In bold type P≤0.05 statistically significant

Table 4 Comparison of biceps brachii and erector spinae SmO2 at the time of CPR at different altitudes before and after conditioning

		F-value	P-value
Biceps brachii SmO2, %	Altitude	0.384	0.689
	Moment	12.644	**0.012**
	Phase	0.236	0.644
	Altitude-moment	1.204	0.334
	Altitude-phase	2.570	0.118
	Phase-moment	4.921	0.068
	Altitude-moment-phase	2.427	0.130
Erector spinae SmO2, %	Altitude	0.311	0.744
	Moment	20.777	**0.020**
	Phase	10.261	0.049
	Altitude-moment	15.349	**0.004**
	Altitude-phase	6.250	**0.034**
	Phase-moment	50.314	**0.006**
	Altitude-moment-phase	9.992	**0.012**

SmO2: Muscle oxygen saturation; Moment: initial and final CPR; Phase: pre and post conditioning
In bold type P≤0.05 statistically significant

ERC Guidelines 2021 (4). The strength necessary to perform thorax compressions with a depth of 5 cm in this device was >28.5 kp. CC quality was obtained from the manikin software and is the result of integrating CC with adequate chest depth, rhythm, and relaxation.

iAltitude Simulator® (Madrid, España) allowed both the simulation of different altitudes (600, 3000 and 5000 m) and the physical conditioning program. It includes a circuit for hypoxia induction and an adjustable face mask (individual use). The FiO2 was 0.21, 0.14 and 0.11 for 600, 3000 and 5000 m, respectively.

Resuscitators' physiological demands during tests were registered using the software iAltitude Trainer® (Madrid, España). SpO2 was measured with a pulse oximeter (Oximeter DF8 W / USB 3018L XPOD, ear clip SNRS 8000Q2; Nonin Medical, Plymouth, EE. UU.) placed on the right earlobe of each participant. HR was measured with a sensor Polar Team H7 (Kempele, Finland) located above the xiphoid process of the sternum (31). A blood pressure monitor was placed on the right arm to monitor BP (OMRON M5- I,Matsusaka, Japan). During the resting phase, each participant had an electrocardiogram, and HR and blood pressure were tested.

2.4. Statistical analysis

Quantitative variables have been described using mean values, standard deviation (SD) and coefficient of variation (CV); absolute frequency and percentages have been used for qualitative variables. The Shapiro–Wilk and Levene tests have been used to check the normal distribution of data and to identify homogeneity of variances. The comparison of means of dependent variables was performed using the paired t-test and independent variables with Student's t test. Practical significance was assessed by calculating the size of Cohen's d-effect for dependent variables between baseline and end-to-end data.

Effect sizes (d) greater than 0.8, between 0.8 and 0.5, between 0.5 and 0.2, and less than 0.2 were considered large, moderate, small, and trivial, respectively (32). Using the analysis of variance of repeated samples (ANOVA), the differences in the values of HR, (%) SmO2 in biceps brachii and erector spinae at the different altitudes before and after conditioning were compared. A statistical relevance was considered only when P value≤0.05. All the statistical analyses were performed with IBM® SPSS® Statisticsv28.

2.5. Ethical considerations

All participants approved to participate with written informed consent. This study respected the ethical principles of the Declaration of Helsinki. The protocol for the study was approved by the Ethics Committee for Investigation with medicinal products of the Integrated Care Management of Albacete, Spain (code 2021-094).

3. Results

Table 1 shows the basic characteristics of the participants comparing both genders. Usual anthropometric differences between both genderss are observed with higher values in the weight, height, and Body mass index (BMI).

Neither of the two muscles showed significant differences in SmO2 at the end of CPR performed at different altitudes before and after conditioning. On the other hand, HR during CPR did show significant differences between the initial and final values after the intervention, but not between altitudes (Table 2).

Table 3 shows the comparison of HR and SmO2 values in biceps brachii and erector spinae during CPR at 600 m with the values obtained at 3000 and 5000 m prior to the conditioning program. There were no differences in SmO2 values of either of the muscles when compared with values at 600 m. Relevant differences (P<0.001) were seen only in HR after CPR at 5000 m (169.1 vs 163.35 at 600 m).

On the other hand, when analyzing the variance of repeated samples considering the effect of conditioning (Table 4), it is obtained that the significant differences are associated in the biceps brachii with the moment in which the SmO2 is obtained (beginning or end of the exposure). In the erector spinae, differences are also observed between before and after conditioning and when the three situations are combined.

Figure 2 shows evolution of biceps brachii and erector spinae SmO2 and quality CC during CPR at different altitudes before and after conditioning.

It is noticeable that, in both muscles, SmO2 values before and after conditioning show a slightly rising trend during CPR, and %SmO2 values are lower at 5000 m. In pre-conditioning, they were 82% at 600 and 5000 m and 89% at 3000. In post-conditioning, the results were 86%, 87% and 89% at 600, 3000 and 5000 m respectively.

4. Discussion

This study analyzed the SmO2 in biceps brachii and erector spinae muscles during a 10-minute CPR at simulated altitudes of 600, 3000 and 5000 m, and the influence of an intervention based on a training program on the SmO2 of muscles and on said altitudes during CPR maneuvers (with help from device Humon Hex®). CPR has been performed on a standardized mannequin with invariable resistance for both muscles independent of the altitude at which CPR was performed (6). The results of this study can be used to better understand the mechanism of how each muscle works during CC and why fatigue sets in.

During preconditioning, HR was higher after CPR at all altitudes, which is reasonable after every effort in physical activity. SmO2 in both muscles followed a similar pattern: it was lower at all altitudes at the beginning of CPR. SmO2 at 600 and 3000 m increased (33-34), however this increase did not recur after CPR at 5000 m, which could be due to a decrease in CC quality, by compressions not being deep enough and thus lower the efforts of the resuscitator, as reported by McDonnals et al. (35).

Over increasing physical effort, SmO2 decreases as reported by Wilkinson et al. (36). In our study, biceps brachii and erector spinae SmO2 did not decrease over CPR performance: effort intensity remains constant while performing CC in compliance with quality criteria; increasing intensity would reduce quality, as it was stated before.

The absence of significant differences when comparing SmO2 at 600 m before and after CPR to SmO2 measurements at 3000 and 5000 m could be reasonable as CPR is a medium effort activity for a medium sized individual and because

CC quality depends greatly on BMI amongst all other factors (7,37-39).

Following the conditioning program, before and after CPR, SmO2 exceeded the values obtained before conditioning in both muscles. Likewise, in our study, following the conditioning program, except for 5000 m altitude, SmO2 in both muscles at 600 and 3000 m was higher than at the end of CPR than at the beginning. This information matches the reports by Wilkinson et al. about physiological demands meaning an increasing effort (35). In our study, the increase in demands were caused by altitude hypoxia, not because of CC efforts. Therefore, we can declare that a conditioning program for hypoxia improves tissue oxygenation in scenarios of physical activity efforts in altitudes (10,40).

Finally, as already stated by Jui-Yi T et al. and proven in our study too, when comparing biceps brachii and erector spinae SmO2 at 10-minute CPR, before and after conditioning, we notice similar SmO2 values, as both muscles participate equally in the execution of CC (5).

The outcomes from this study can be useful to better understand the participation of muscle groups in CC during CPR, and fatigue, which reduces the quality of CC. NIRS devices connected to screens (watch, tablet, etc.) may be applied to report resuscitators in real time about low oxygenation levels in muscles and when resuscitators need to switch places in order to maintain the quality of CC.

5. Limitations

As for limitations in our study, we would mention the small sample size, which was due to the complexity of the intervention and duration of the conditioning program for hypoxia. Moreover, unlike the biceps brachii muscles, the erector spinae muscle movement in CC might have interfered with registration and collection of SmO2 values. Another limitation was lacking measurement of adipose tissue in the areas where portable NIRS devices were placed, since a higher amount of adipose tissue affects penetration of the source light and thus data analysis by the devices using NIRS as well.

6. Conclusion

We conclude that NIRS use allows developing an optimum training plan, making the resuscitator aware of the effort they can make without exceeding any limit and by optimizing performance.

The improvement in physical performance and recovery capacity induced by intermittent hypoxia conditioning programs increases the quality of CPR in prolonged cardiac arrests and in adverse conditions, such as at high altitudes.

7. Declarations

7.1. Acknowledgement

None.

7.2. Authors' contribution

SP-G: Conceptualization (equal), formal analysis (equal), methodology (equal), project administration (lead), software (equal), supervision (equal), writing review editing (lead); AL-G: Conceptualization (equal), methodology (equal), resources (equal); CMG-A; formal analysis (equal), methodology (equal), software (equal), supervision (equal), validation (equal); IMG-R: Conceptualization (equal), methodology (equal), resources (equal); CMG-A; formal analysis (equal), methodology (equal), software (equal), supervision (equal), validation (equal); JL-T: Conceptualization(equal), methodology (equal), project administration (lead), resources (equal), supervision (lead), writing review editing(lead). FG-A: Conceptualization (equal), data curation (lead), formal analysis (equal), investigation (equal), resources (equal), writing original draft (lead); IM-GM: Conceptualization (equal), data curation (lead), formal analysis (equal), investigation (equal), resources (equal), writing original draft (lead); JR-S: Conceptualization (equal), data curation (lead), formal analysis (equal), investigation (equal), resources (equal), writing original draft (lead).

7.3. Conflict of interest

The authors of this paper declare that there were no conflicts of interest.

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