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Original Article

# Heart rate deflection point as a non-invasive method to determine the anaerobic threshold in trained elderly women in the aquatic environment

## Ponto de deflexão da frequência cardíaca como método não invasivo para determinar o limiar anaeróbio no meio aquático em idosas treinadas

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ABSTRACT

**Introduction:** The anaerobic threshold (AT) determination is important for individualizing the aerobic training prescription. **Objective:** To compare and verify the agreement between oxygen uptake ($VO_2$), heart rate (HR), and rate of perceived exertion (RPE) at the AT determined by the ventilatory threshold (VT) and heart rate deflection point (HRDP) methods during an aquatic incremental test in trained older women. **Methods:** Nine elderly women (64.3 ± 4.4 years) engaged in a water-based training program in the last three months performed a maximum incremental test using the water-based stationary running exercise. The test started at a 70 $b.min^{-1}$ cadence for 2 min, followed by 15 $b.min^{-1}$ increments every 2 min until exhaustion. $VO_2$, HR and RPE were measured throughout the test and the AT was identified for each method (i.e., VT and HRDP) by three experienced physiologists. Paired t-test and Bland-Altman analysis were used for data analysis ($\alpha$=0.05). **Results:** There was no difference between the VT and HRDP methods ($p>0.05$) and the Bland-Altman analysis showed acceptable agreement between them for all investigated outcomes ($VO_2$: 22.9 ± 5.1 vs. 23.5 ± 4.7 $ml.kg^{-1}.min^{-1}$, IC95%: -3-+4 $ml.kg^{-1}.min^{-1}$; HR: 147 ± 11 vs. 147 ± 11 bpm, IC95%: -9-+8 bpm; RPE: 16 ± 1 vs. 16 ± 1, IC95%: -2-+3). **Conclusion:** Based on these findings, both HR and RPE determined by the HRDP can be used as valid parameters and practical tools for field prescription of intensity during water-based exercises in elderly trained women.

**Key-words:** Exercise, Aging, Exercise test, Hydrotherapy, Oxygen consumption.

RESUMO

**Introdução:** A determinação do limiar anaeróbio (LAn) é importante na individualização da prescrição do treinamento aeróbio. **Objetivo:** Comparar e verificar a concordância das respostas de consumo de oxigênio ($VO_2$), frequência cardíaca (FC) e índice de esforço percebido (IEP) correspondentes ao LAn determinado através dos métodos ventilatório (LV) e ponto de deflexão da frequência cardíaca (PDFC) durante um teste incremental no meio aquático realizado por idosas treinadas. **Métodos:** Nove idosas (64,3 ± 4,4 anos), engajadas em um programa de hidroginástica nos últimos três meses, realizaram um teste máximo incremental com o exercício de corrida estacionária. O teste iniciou com uma cadência de 70 $b.min^{-1}$ durante 2 min, seguida de aumentos de 15 $b.min^{-1}$ a cada 2 min até a exaustão. Dados de $VO_2$, FC e IEP foram medidos ao longo do teste. O LAn foi identificado para cada método por três fisiologistas experientes. Teste T pareado e análise de Bland-Altman foram utilizados para a análise dos dados ($\alpha$=0,05). **Resultados:** Não houve diferença entre os métodos LV e PDFC ($p>0,05$) e a análise de Bland-Altman demonstrou concordância aceitável entre eles para todas as variáveis analisadas ($VO_2$: 22,9 ± 5,1 vs. 23,5 ± 4,7 $ml.kg^{-1}.min^{-1}$, IC95%: -3-+4 $ml.kg^{-1}.min^{-1}$; FC: 147 ± 11 vs. 147 ± 11 bpm, IC95%: -9-+8 bpm; IEP: 16 ± 1 vs. 16 ± 1, IC95%: -2-+3). **Conclusão:** Com base nesses achados, sugere-se que a FC e o IEP determinados pelo PDFC podem ser utilizados como parâmetros válidos e ferramentas práticas de campo para a prescrição de intensidade de exercícios de hidroginástica em idosas treinadas.

**Palavras-chave:** Exercício físico, Envelhecimento, Teste de esforço, Hidroterapia, Consumo de oxigênio.

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## Introduction

Immersion in the aquatic environment exposes the body to conditions that are different from those on land, mostly due to water's hydrostatic pressure and thermal conductivity [1]. These differences lead to changes in cardiovascular, neuroendocrine and metabolic responses [2,3], impacting maximal and submaximal heart rate (HR) and oxygen consumption ($VO_2$) responses [4,5]. Therefore, the assessment and prescription of exercises in the aquatic environment must consider these changes to ensure an adequate control of training intensity in this environment. Hence, one of the most accurate, individualized, and recommended forms of prescription for training in the aquatic environment is the utilization of the HR or the rating of perceived exertion (RPE) considering its association to the anaerobic threshold (AT) determined in water [6–8]. The rationale behind this recommendation lies within the fact that the AT is the transition point between the predominance of the aerobic to anaerobic system and can be used as a more precise and individualized way to prescribe the intensity of aerobic exercises [9].

However, the gold standard measures for AT determination (ventilatory or lactate methods) require sophisticated equipment, are considered costly procedures for large-scale use (gyms and sports clubs), and lactate determination is also considered an invasive procedure. Therefore, the HR deflection point (HRDP) can be considered as a more practical, less costly and non-invasive method to determine the AT, as it is based on the curvilinear relationship between HR and exercise workload [10]. This method has been validated in land running [10] and was subsequently applied in several protocols and populations on that environment [11-15]. More recently, the use of the HRDP to determine the AT in aquatic exercises has received attention, but so far, the protocols have only been developed and applied in young individuals. Based on these studies, both physiological (HR and $VO_2$) and psychophysiological (RPE) parameters associated to the HRDP have been shown to be similar and valid compared to those determined based on the second ventilatory threshold (VT) [16-18] or lactate threshold (LT) [19]. These parameters, however, have not been investigated in neither older adults or individuals previously trained in water aerobics. It is known that aging may have a negative impact on cardiorespiratory fitness [20], potentially reducing both maximal and submaximal HR and $VO_2$ (e.g., AT). Water-based aerobic programs, on the other hand, have been shown as an important tool for minimizing such losses, improving cardiorespiratory, neuromuscular, and functional outcomes, as well as quality of life, in older individuals [7,21]. These exercises are also traditionally indicated to the older population because they provide a lower impact on lower limb joints [22] and cardiovascular overload [23] when compared to the land environment.

Thus, considering that HR and RPE have been widely used to control intensity during water fitness training sessions in older individuals [7,24-28], its determination associated with the AT becomes fundamental. In addition, the intensity prescription based on the RPE is simple and easily applicable during group classes. It is, therefore, important to investigate the validity of using these variables determined based on the HRDP compared to the gold standard method for aquatic exercise prescription in water-based programs performed by older individuals in order to guarantee a safe and efficient prescription for this population. This characteristic is even more important in trained older women because the control of water fitness training load in these individuals becomes even more necessary after the initial adaptations typically observed during the first few weeks of training. An adequate prescription of the exercise training loads throughout the training program is, therefore, crucial to attend to the biological individuality so that this population continues to obtain positive adaptations in their physical conditioning. Thus, the purpose of present study was to compare and verify the agreement between $VO_2$, HR and RPE measures associated to the AT determined based on the VT and HRDP methods during a maximum test in the aquatic environment in trained older women. Our hypothesis was that both HR and RPE would be similar between the two methods investigated, resulting in an acceptable agreement between the HRDP and VT methods.

## Methods

### *Participants*

The sample consisted of nine physically active older women (64.3 ± 4.4 years; 69.7 ± 7.7 kg; 151.1 ± 4.6 cm; 30.6 ± 4.1 kg/m$^2$). These participants were recruited from the Effects of two water-based aerobic training programs in elderly women study (WATER Study), in which all of them completed a three-months aerobic training program in the aquatic environment with two 45-min weekly sessions [7,21]. Exclusion criteria for participation in the WATER study included history of cardiovascular disease (except for controlled hypertension) and/or osteoarticular limitations for exercise practice. Participants in the present study were also excluded based on use of betablocker medication. Participants who completed the second training phase were invited and those who volunteered participated in the present study. The study was approved by the research ethics committee (CAAE: 69931817.5.0000.5313). All participants were informed about the study procedures and signed a consent form.

### *Procedures*

Previous to the experimental session, body mass and height measurements were obtained using a digital scale (WELMY, Santa Bárbara d'Oeste, Brazil) with a stadiometer, which were used to calculate the body mass index (BMI) based on the equation: BMI = body weight (kg)/height$^2$ (m). All participants were asked to abstain from caffeine or any other stimulant, as well as to avoid intense physical activity 24 h prior to the experimental session.

The experimental session included a water-based maximal incremental test using the stationary running exercise, like those previously employed in young women [4,8,16,17,29-31]. Participants already knew the exercise technique, as it was included in all training sessions of the WATER Study. Initially, each participant was familiarized with the test procedures, which also served as warm-up. Specifically, the test included the performance of the stationary running exercise in the water environment using an adequate range of motion (90º hip and knee flexion), while maintaining a specified cadence reproduced on the app Metronome. As the lower limb movements are performed in an alternated fashion (i.e., one limb flexes while the contralateral limb extends), each phase corresponded to a beat of the metronome. Participants also received standardized instructions about the Borg's 6-20 RPE scale [32], which they were already familiarized as it was used for exercise intensity control during the WATER Study. The protocol was performed with the participants barefoot and immersed to the depth of the xiphoid process. Water temperature was maintained at 32ºC and the test as monitored by three experienced instructors, one inside and two outside the pool.

The test began at a cadence of 70 $b.min^{-1}$ for 2 min, followed by 15 $b.min^{-1}$ increments every 2 min, a protocol that was adapted for older women based on previous studies [16,31]. Tests were performed to volitional exhaustion or when participants were not able to maintain cadence at the intended level. Range of motion and technique of execution were visually controlled by an experienced instructor, who gave constant feedback to the subjects along the test. Gas exchange was measured at a 3-breath average using a portable gas analyzer (VO2000, MedGraphics, Ann Arbor, USA), which was previously calibrated according to the manufacturer's specifications. HR data were obtained continuously using a HR monitor (FT1, Polar, Finland) and registered at every 15 s. Finally, the RPE was measured immediately after each stage of the maximal incremental test using Borg's 6-20 scale [32]. The scale (21 x 29,7 cm) was presented to the participants so that they could choose the number corresponding to their RPE. Maximal incremental tests were considered as valid when at least two of the following criteria were met: a) plateau in $VO_2$ despite an increase in exercise intensity; b) respiratory exchange ratio greater than 1.15; c) maximal respiratory frequency greater than 35 breaths per minute [33]; e d) RPE equal or greater than 18.

Finally, the AT was identified for each participant using both the VT and HRDP methods. The first was determined based on the ventilation by intensity graph and confirmed by the ventilatory equivalent of carbon dioxide ($VE/VCO_2$) [34]. The HRDP, in turn, was determined based on the HR by intensity curve, and was considered as the downward deflection point from the linear HR-intensity relationship [10]. Both the VT and HRDP were determined by visual inspection by three experienced physiologists in a blinded fashion. In case of no agreement between them, the median value was used for analysis. Following AT determination, the $VO_2$, HR and RPE values associated to the AT were identified based on both the VT ($VO_{2VT}$, $HR_{VT}$ and $RPE_{VT}$) and HRDP ($VO_{2HRDP}$, $HR_{HRDP}$ e $RPE_{HRDP}$) methods and used for analysis.

### *Statistical analysis*

Data are presented using descriptive statistics (mean ± SD). Normality was tested using the Shapiro-Wilk test. Paired samples t-tests were used to compare $VO_2$, HR and RPE between the VT and HRDP methods. To verify the agreement between methods, the differences were plotted against the mean value for each variable, as suggested by Bland and Altman [35,36]. This analysis is based on the differences between measurements in the same individual by the two methods. The mean difference in the Bland-Altman plot corresponds to the estimated bias, the systematic difference between methods, and the SD of the differences measures random fluctuations around this mean. The 95% limits of agreement were estimated by mean difference plus or minus 1.96 SDs of the differences, which explain how far apart measurements by the two methods were likely to be for most individuals. All statistical tests were performed using the SPSS statistical package (version 20.0) and the significance level adopted was $\alpha = 0.05$.

## Results

All participants were able to complete the maximal test and no adverse events were observed. The descriptive data regarding the outcomes obtained during the incremental test are summarized in Table I.

**Table I -** Maximal oxygen uptake ($VO_{2max}$), heart rate ($HR_{max}$), rating of perceived exertion ($RPE_{max}$) and cadence responses corresponding to the maximal effort during a maximal test in the aquatic environment.

| Variables | Mean ± SD |
|---|---|
| $VO_{2max}$ (ml.kg$^{-1}$.min$^{-1}$) | 26.82 ± 5.37 |
| $HR_{max}$ (bpm) | 159.33 ± 11.02 |
| $RPE_{max}$ | 18.44 ± 1.59 |
| Maximal cadence (b.min$^{-1}$) | 141.67 ± 14.58 |

The HRDP was clearly identified in all the investigated participants (100%; n = 9). The values of $VO_2$, HR and RPE associated to the AT showed similar values between the VT and HRDP methods and are shown in the Table II. According to the Bland-Altman analysis, an acceptable agreement between the VT and HRDP methods was verified for all variables, with non-significant r values indicating that the bias is not proportional ($VO_2$: r = -0.18, IC95%: -3.07 to 4.25 ml.kg$^{-1}$.min$^{-1}$, p = 0.64; FC: r = -0.12, IC95%: -8.93 to 8.27 bpm, p = 0.76; IEP: r = 0.21, IC95%: -1.86 to 2.52, p = 0.58). Therefore, it was estimated that for 95% of the individuals, $VO_{2HRDP}$ was within 3.07 ml.kg$^{-1}$.min$^{-1}$ below $VO_{2VT}$ and 4.25 ml.kg$^{-1}$.min$^{-1}$ above it (Figure 1A). Likewise, it was estimated that the $HR_{HRDP}$ was within 8.93 bpm below and 8.27 bpm above $HR_{VT}$ (Figure 1B). As for RPE, it was estimated that, for 95% of individuals, the $RPE_{HRDP}$ was within 1.86 below the $RPE_{VT}$ and 2.52 above it (Figure 1C).

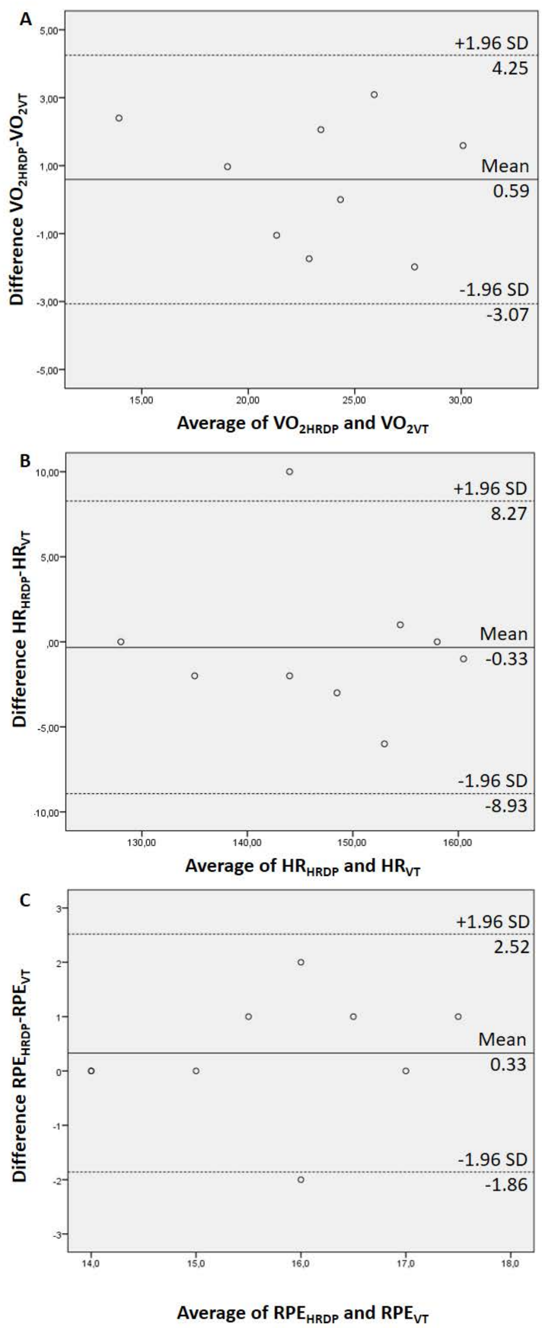
**Table II -** Oxygen uptake ($VO_2$), heart rate (HR) and rating of perceived exertion (RPE) values associated to the anaerobic threshold determined based on the ventilatory threshold (VT) and the heart rate deflection point (HRDP) methods during a maximal incremental test in the aquatic environment.

| | VT | HRDP | P |
|---|---|---|---|
| **$VO_2$ (ml.kg$^{-1}$.min$^{-1}$)** | 22.89 ± 5.05 | 23.49 ± 4.72 | 0.368 |
| **HR (bpm)** | 147 ± 11 | 147 ± 11 | 0.825 |
| **RPE** | 16 ± 1 | 16 ± 1 | 0.397 |

## Discussion

The main finding of the present study was that the $VO_2$, HR and RPE associated to the AT showed similar values and agreement between the VT and HRDP methods during a maximal incremental test performed in the aquatic environment by trained older women. These results suggest that the HRDP, as proposed by Conconi *et al*. [10], is a valid method to determine the AT and can assist in the prescription of intensity during water aerobics sessions performed by older women.

Similar values of $VO_2$ and HR were observed between VT (22.9 ± 5.1 ml.kg$^{-1}$.min$^{-1}$ e 147 ± 11 bpm) and HRDP (23.5 ± 4.7 ml.kg$^{-1}$.min$^{-1}$ e 147 ± 11 bpm) methods in the present investigation. These results are in accordance with previous studies demonstrating similar $VO_2$ and HR values associated to the AT determined by these two methods in water-based exercises (stationary running, frontal kick, and cross-country skiing) performed by young women [16,17]. However, such studies have not verified the agreement between the methods through the Bland-Altman analysis, which is the currently indicated method for determining whether the two measures are equivalent and whether one can replace the other [36].




$VO_{2HRDP}$ = $VO_2$ determined by the HRDP method; $VO_{2VT}$ = $VO_2$ determined by the VT method; $HR_{HRDP}$ = HR determined by the HRDP method; $HR_{VT}$ = HR determined by the VT method; $RPE_{HRDP}$ = RPE determined by the HRDP method; $RPE_{VT}$ = RPE determined by the VT method.

**Figure 1 -** Bland-Altman plots with estimated mean bias and 95% limits of agreement for differences in oxygen uptake ($VO_2$; panel A), heart rate (HR; panel B) and rating of perceived exertion (RPE; panel C) data between the heart rate deflection point (HRDP) and ventilatory threshold (VT) methods, as plotted against the mean value, during the water-based stationary running exercise.

The study by Pinto *et al*. [18] also observed similar $VO_2$ and HR values associated to the AT between the VT and HRDP methods determined in a water cycling protocol in young men. In turn, this study also analyzed and found the agreement between these methods using the Bland-Altman analysis. Additionally, Alberton *et al*. [19] found similar values and agreement on the HR value associated to the AT during a water-based stationary running maximal incremental test performed by young men, but the comparison was between the HRDP and LT methods. Therefore, the present study corroborates the previous literature related to the use of $HR_{HRDP}$ in maximal tests performed in the aquatic environment by young individuals as a valid indicator of AT determination, expanding these results to trained older women.

Incremental maximal tests involving specific water-based exercises have been investigated in the literature, with the determination of HR and $VO_2$ values at maximum and associated to the first and second ventilatory thresholds in young [4,16,17,30,31] and postmenopausal women [5]. In addition, the significant relationship between these parameters have been verified throughout the test [29]. Within this context, the present results are important because they add to the literature the possibility of determining the HRDP during the maximal incremental aquatic test with the stationary running exercise as an efficient strategy also for the evaluation of trained older women. It should also be noted that after the initial adaptations arising from the first few weeks of water aerobics training, workload readjustment is fundamental so that individuals can keep improving with training. Therefore, in trained older women the possibility to determine the AT and use $HR_{HRDP}$ as a parameter to prescribe intensity in water fitness classes is an important alternative to attend the principle of biological individuality in a practical and accessible way. Thereby, the $HR_{HRDP}$ can be determined from a simple, inexpensive and non-invasive test, using only a HR monitor and a metronome during a structured maximal incremental test for the aquatic environment, as performed in the present study. Based on the $HR_{HRDP}$, it is possible to calculate percentages below or above the AT to prescribe the intensity of the desired training zone [9] in water fitness sessions performed by older women.

As for the RPE, the present study demonstrated similar values between the VT (16 ± 1) and HRDP (16 ± 1) methods, as well as agreement in the RPE associated to the AT results determined by the two methods. The study by Alberton *et al.* [19] seems to have been the first study to investigate the agreement between RPE determined by the HRDP and the LT, the gold standard method of determining the AT. Contrary to the findings of the present study however, Alberton *et al.* [19] did not observe an agreement in the RPE associated to the AT determined by the LT and HRDP methods in a water-based stationary running maximal incremental test performed by young men. Two aspects can be highlighted to possibly explain the disagreement of the results between these studies. First, the different gold standard measures used (VT vs. LT, respectively) require the application of different stage lengths during the incremental test (2 min vs. 3 min stages) and were sampled at different sampling rates (3-breath average for gas exchange vs. one measure at the end of each stage for lactate). In addition, the difference between the participants included in both studies should be highlighted, as those included in the present investigation were trained older women that had been previously enrolled in a 3-month water-based training program prescribed based on Borg's RPE scale. Alberton *et al.* [19], on the other hand, included young men, but there is no report on the use of the scale in the participants' training routine (only familiarization before the test). As such, familiarization with the Borg's scale, as well as the standardization of the instruction that will be given prior to using it, is important.

Considering the significant association between RPE and physiological parameters such as HR and $VO_2$ when determined during a water-based incremental test, there is a strong body of evidence supporting the use of RPE to control training intensity during water aerobics exercises [8,29]. Moreover, it has been previously shown that values close to 16 on the Borg 6-20 Scale correspond to the intensity at the AT in young women performing the stationary running in the aquatic environment [8,31]. Thereby, the $RPE_{HRDP}$ values observed by us (i.e., 16) confirm and expand these findings to trained older women as well. It is noteworthy to mention that prescribing exercise intensity based on the RPE has the advantage of possessing greater external validity, as it allows one to prescribe the training intensity in clinical populations like those using drugs that affect HR. In addition, using RPE facilitates prescribing intensity during water fitness classes with a large number of individuals, such as those in gyms and sports clubs, where performing a maximal incremental test is not always feasible.

Some limitations of the present study should be highlighted. First, we only investigated the water-based stationary running exercise. Although it currently is the most frequently used exercise in water fitness classes, it is possible that other exercises may present slightly different responses. Thus, caution is needed when extrapolating our results to other water-based exercises. In addition, the results of the present study are also limited to trained older women, which were familiarized with water-based training programs and familiar with such classes using RPE. We also recognize the sample size as a possible limitation, even though our results seemed to agree with the current available literature. Thus, further investigations about the determination of AT by HRDP should be carried out with other exercises and in other populations to expand and support our findings.

## Conclusion

Based on the results of the present study, $VO_2$, HR and RPE variables showed similar values and agreement when determined based on both the VT and HRDP method. Accordingly, the use of HRDP can be considered a valid parameter to determine the AT during a water-based stationary running maximal incremental test in trained older women. Therefore, the HR determined by the HRDP can improve the prescription of intensity parameters in the aquatic environment through a simple, inexpensive and non-invasive test. Likewise, the observed RPE values associated to the AT can be adopted as reference for the prescription of water aerobics classes, since this is a simple method and easily applicable during group classes in the aquatic environment.

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**Potential conflict of interest**
No conflicts of interest have been reported for this article.

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**Authors' contributions**
**Conception and design of the research:** Andrade LS and Alberton CL. **Data collection:** Häfele MS, Schaun GZ, Rodrigues SN and Gomes MB. **Analysis and interpretation of data:** Andrade LS, Häfele MS, Schaun GZ, David GB, Pinto SS and Alberton CL. **Statistical analysis:** Andrade LS and Alberton CL. **Obtaining financing:** Alberton CL. **Writing of the manuscript:** Andrade LS and Alberton CL. **Critical revision of the manuscript for important intellectual content:** Häfele MS, Schaun GZ, Rodrigues SN, Gomes MB, David GB and Pinto SS.

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