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ORIGINAL RESEARCH

The influence of respiratory muscle strength on the isocapnic buffering phase in elite orienteering athletes

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Abstract. This study aims to investigate the effect of respiratory muscle strength on the isocapnic buffering phase (IBP) in elite orienteering athletes. Orienteering is a sport that requires both physical endurance and mental focus. It demands high performance on varied terrains, and therefore, athletes are expected to have well-developed aerobic and anaerobic systems as well as respiratory functions. In the study, data on maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), and gas exchange variables from 20 elite male athletes were analyzed. The IBP was evaluated through parameters such as the ventilatory threshold (VT) and the respiratory compensation point (RCP). The IBP represents the period between the VT and the RCP, during which the body balances metabolic acidosis. According to the findings, MIP and MEP values had a significant effect on VCO_2 production at VT and RCP. However, the same relationship was not observed for maximal oxygen consumption (VO_{2max}) and the IBP area. Nonetheless, a borderline significant relationship was found between MIP and the IBP phase ($p< 0.055$), suggesting a potential tendency that may become significant in studies with larger sample sizes.

Introduction

Orienteering is a physically demanding sport conducted over three distinct distances (sprint, middle, and long), with winning times ranging from 12 to 75 minutes. During competitions, orienteering athletes must maintain a high level of physical fitness. This requirement stems from the need to sustain peak performance across varying types of terrain and vegetation. While managing mental processes such as route planning and map reading, athletes must also adapt to these environmental differences. Accordingly, they exhibit a constantly shifting balance of aerobic and anaerobic metabolism based on their physical capacities (Batista et al., 2020).

Orienteers typically possess high maximal oxygen uptake and running speed capacities. Studies have shown that elite orienteering athletes reach approximately 85–90% of their maximum oxygen uptake (VO_{2max}) and about 90% of their maximal heart rate during competition (Bird et al., 1993; Larsson et al., 2002; Gjerset et al., 1997). Although running speed varies according to terrain type and difficulty level, it is widely accepted that elite athletes possess substantial metabolic adaptations necessary for success. In terms of anaerobic capacity, they are reported to have thresholds at or above the anaerobic threshold (Gjerset et al., 1997).

VO_{2max}, ventilatory threshold (VT), and respiratory compensation point (RCP) are important physiological indicators used to assess aerobic fitness, training adaptations, and endurance training planning in athletes (Cunha et al., 2016). The VT, measured via gas exchange data, represents the point during incremental exercise when anaerobic metabolism begins to contribute substantially to overall metabolism (Wasserman et al., 2012). Beyond the VT, the buffering of H^+ ions by blood bicarbonate increases the production of non-oxidative VCO_2 (Wasserman et al., 2012).

As exercise intensity further increases, the body's buffering systems become overwhelmed, resulting in a drop in blood pH and heightened stimulation of hyperventilation (Binder et al., 2008; Oshima et al., 1998; Wasserman et al., 2012). This triggers a second ventilatory threshold known as the RCP (Meyer et al., 2004; Whipp et al., 1989). Physiologically, the RCP marks the failure of the body's buffering mechanisms (Meyer et al., 2004). The period between the VT and the RCP is referred

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to as the isocapnic buffering phase (IBP), representing the compensatory phase against exercise-induced metabolic acidosis (Takano, 2000; Whipp et al., 1989). The phase between the RCP and the point of exhaustion is termed the hypocapnic hyperventilation (HHV) phase (Chicharro et al., 2000; Oshima et al., 1998).

The duration of the IBP may be linked to factors such as buffering capacity, lactate metabolism, and the sensitivity of the carotid bodies to metabolic acidosis during exercise (Hasanli et al., 2015; Rausch et al., 1991; Whipp et al., 1989). Some studies report that a longer IBP positively contributes to athletes' aerobic capacity (Oshima et al., 1997; Hirakoba & Yunoki, 2002), while others argue that there is no significant relationship between the IBP and endurance performance (Bentley et al., 2005). More recent research suggests that the IBP may serve as an indicator of both aerobic and anaerobic capacity in athletes (Hasanli et al., 2015).

The increasing ventilatory demand during exercise is met by the respiratory muscles. During moderate exercise, alveolar ventilation rises in parallel with metabolic needs, and arterial blood gas tensions and acid-base balance are maintained close to resting levels. During maximal exercise, the oxygen consumption of respiratory muscles accounts for approximately 10% of total oxygen uptake (Aaron et al., 1992).

Studies examining the relationship between respiratory muscle strength and VO_{2max} have produced mixed results. Klusiewicz (2014) found no correlation between maximal inspiratory pressure (MIP) and absolute or relative VO_{2max} in male athletes, but did find such a correlation in female athletes. Juric et al. reported a significant relationship between MIP and VO_{2max} in basketball and handball players. In contrast, Deliceoğlu et al. (2024) found no significant relationship between MIP, maximal expiratory pressure (MEP), and $VO_{2max.}$

Lomax et al. (2011) reported that inspiratory muscle training and warm-ups (at 40% of maximal inspiratory muscle strength) improved Yo-Yo test performance in two groups of male football players compared to a control group. Volianitis et al. (2001), in a study on female rowers, observed higher $VO_{2max.}$ values in the experimental group following inspiratory muscle warm-up exercises combined with sport-specific general warm-up routines.

Given this context, the present study seeks to answer whether respiratory muscle strength affects the isocapnic buffering phase, one of the sub-parameters of $VO_{2max.}$ and a recognized performance indicator in endurance athletes. Based on the existing literature, we aim to address this question and emphasize the often-overlooked importance of respiratory muscle strength in sports performance a field where success frequently depends on seemingly small factors.

Materials and Methods

Research Design

This study employed a quantitative research design, which enables the observation, measurement, and numerical expression of phenomena and events in an objective manner.

Participant Selection

Twenty athletes classified as elite ($VO_{2max.} \geq 55$ ml/kg/min) with at least five years of training experience were included in the study. Within the scope of the referenced article, the number of our sportmen are limited as there is 20 sportmen who performs at high level ($VO_{2max} > 55$ dk/ml/kg) in Turkish Oriantiring Federation (Cipryan et.al, 2017).

Inclusion criteria were: non-smokers without a history of respiratory diseases such as asthma, pulmonary tuberculosis, emphysema, or chronic bronchitis. Athletes taking any medications, especially cardiac glycosides or β-receptor antagonists, were excluded from the study. Athletes meeting the study criteria were evaluated on the same day. Demographic data of the participants (age, years of sporting experience, smoking habits, medication use) were recorded.

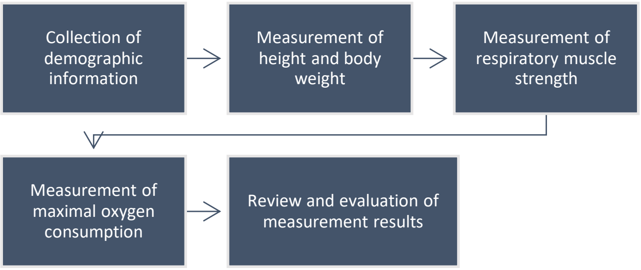
Data Collection Tools

Respiratory muscle strength was assessed using a digital spirometer (Pony FX Cosmed, Italy). VO_{2max} was measured using a cardiopulmonary exercise testing system (Cosmed K5, Italy, Serial No: 2019030706). A Seca stadiometer with ± 1 mm precision was used to measure height, and a Seca (761) mechanical scale was used to measure body mass. A motorized treadmill (H/p/cosmos pulsar, Switzerland) was utilized for the graded exercise tests.

Data Collection Procedures

After recording the athletes' demographic data, their height and weight were measured. Then, to assess respiratory muscle strength, MIP and MEP tests were performed. $VO_{2max.}$ measurements were conducted on a treadmill, and data were collected via the CPET K5 system.

Table 1. Research design workflow diagram



Assessment of Respiratory Muscle Strength and Oxygen Consumption

MIP and MEP tests were applied to assess respiratory muscle strength. For the MIP test, participants were instructed to first completely exhale the air from their lungs, followed by a rapid, deep, and forceful inhalation to fill the lungs completely. For the MEP test, athletes were asked to fully inflate their lungs and then exhale as forcefully and quickly as possible. Each test was performed five times with rest intervals between trials. The data were recorded, and the best result from each test was used for analysis (Sachs et al., 2009).

$VO_{2max.}$ was measured using a portable cardiopulmonary exercise testing system (Cosmed K5, Italy, Serial No: 2019030706), known for its precision in automatic gas analysis of expiratory air. The accuracy of the device calibration was verified using a certified gas mixture (5.0% CO_2 and 16.0% O_2). To minimize environmental impacts on performance, laboratory conditions were strictly controlled with temperatures maintained between 18–23°C and relative humidity kept below 70% (Weakley et al., 2024).

In treadmill protocols used for aerobic capacity and power measurements, the participants' running performance was monitored according to established termination criteria. For VO_{2max} determination, after a 2-minute warm-up at 6 km/h, the treadmill speed was increased by 1 km/h every 90 seconds, and the incline was raised by 0.5% alongside each speed increment (Deliceoglu et al..2024).

The test concluded once it was clear the athlete had reached their maximum oxygen uptake, confirmed by the presence of at least three indicators occurring at the same time: a rating of perceived exertion of 17 or higher on the original Borg scale along with verbal confirmation of fatigue; a plateau in oxygen consumption despite increasing intensity; a respiratory quotient (RQ) of 1.15 or above; a heart rate surpassing 85% of the athlete's maximum; and no further rise in heart rate with additional workload.

Aerobic capacity was assessed using a portable automatic gas analyzer, and the average values from the final 30 seconds of the exercise phase were adjusted for body weight (Gocentas et al., 2011). Throughout gas analysis, minute ventilation (V_E), VO_2, and VCO_2 were measured directly. The oxygen consumption recorded during the last 30 seconds of effort was taken as the $VO_{2max.}$

To determine both VT and the RCP, the V-slope method was applied, following the approach by Beaver, Wasserman, and Whipp (1986). The VT was identified through a VO_2 versus VCO_2 plot, while the RCP was found by graphing VCO_2 against V_E. Linear regression helped pinpoint the intersection points corresponding to VT and RCP, and the respective VO_2 and VCO_2 values (expressed in ml/kg/min), along with associated running durations, were documented.

For calculating the isocapnic buffering phase (IBP) area, average respiratory parameters were logged every 5 seconds across resting, exercise, and recovery stages. The difference in VCO_2 production between the VT and RCP was computed, and the trapezoidal method was used to generate the isocapnic buffering area curve.

The formula used was as follows:

- **Formula**: $(y_1 + y_2) \div 2 \times (x_2 - x_1)$
- **y_1, y_2**: CO_2 production (L/min)
- **x_1, x_2**: time (seconds)

$$A = \sum_{i=1}^{n-1} A^1 = \sum_{i=1}^{n-1} \frac{(y_1 + y_{1+1})}{2} \times (x_{i+1} - x_1)$$

Example of Trapezoidal Area Calculation;

1. First Trapezoid Area (0–1 minute):

$A_1 = (1.0 + 1.5) / 2 \times (1 - 0) = 1.25$

2. Second Trapezoid Area (1–2 minutes):

$A_2 = (1.5 + 2.0) / 2 \times (2 - 1) = 1.75$

3. Third Trapezoid Area (2–3 minutes):

$A_3 = (2.0 + 2.5) / 2 \times (3 - 2) = 2.25$

4. Fourth Trapezoid Area (3–4 minutes):

$A_4 = (2.5 + 2.8) / 2 \times (4 - 3) = 2.65$

To determine VCO_2 production during the hypocapnic hyperventilation phase ($HHVCO_2$), the difference in VCO_2 between the end of exercise and the RCP was calculated and expressed as relative values (Oshima, Tanaka, & Miyamoto, 1998).

Data Analysis

The data obtained from the athletes were analyzed using the SPSS statistical package. The significance level was set at $p \leq 0.05$. To explain the relationship between dependent and independent variables and to determine how much variance in the dependent variable could be explained by the independent variables, linear regression analysis was performed.

Results

The findings from the tests conducted on the study group are presented below in tables, along with their interpretations.

Table 2. Demographic Characteristics of Elite Male Orienteering Athletes

Parameters	**Mean**	**SD**
Age (years)	28.30	5.36
Height (cm)	175.78	5.79
Weight (kg)	69.08	5.75
Sports Experience (years)	11.21	6.88
Weekly Training Frequency (days/week)	5.82	1.26
Daily Training Duration (hours/day)	2.26	.83

***SD:** Standart Deviation*

Table 3. Regression Analysis Results of CO_2 Production Values in Elite Male Orienteering Athletes

	Model	**Unstandardized Coefficients**		**Standardized Coefficients**						
		B	**Std.Dev.**	**Beta**	***t***	**Sig.**	R	R^2	$F_{(2-20)}$	***p***
$RCPCO_2$ (kg/ml/min)	Constant	5.696	8.443		6.004	0.000	.525	.275	.801	.040*
	MIP (cmH_2O)	0.177	0.077	0.476	2.307	0.032*				
	MEP (cmH_2O)	-0.094	,041	-0.470	-2.281	0.034*				
$VTVCO_2$ (kg/ml/min)	Constant	47.378	5,976		7.929	0.000	.630	.396	6.564	.006*
	MIP (cmH_2O)	0.114	0.054	0.394	2.095	0.049*				
	MEP (cmH_2O)	-0.103	0.029	-0.665	-3.534	0.002*				
$MaxCO_2$ (kg/ml/min)	Constant	63.480	11.811		5.375	0.000	.403	.162	1.939	.170
	MIP (cmH_2O)	0.159	0.107	0.328	1,480	0.154				
	MEP (cmH_2O)	-0.102	0.058	-0.392	-1,768	0.092				
$HHVCO_2$ (kg/ml/min)	Constant	12.784	7.389		1,730	0.099	0.099	0.010	0.098	0.907
	MIP (cmH_2O)	-0.018	0.067	-0.065	-,269	0.791				
	MEP (cmH2O)	-0.008	0.036	-0.053	-,221	0.827				

Respiratory Compensation Point (RCP), Carbon Dioxide (CO_2), Ventilatory Threshold Oxygen Volume (VT$\dot{V}O_2$), Maximum Carbon Dioxide Production (Max CO_2), Hypocapnic Hyperventilation Volume (HHV), Maximal Inspiratory Pressure (MIP), Maximal Expiratory Pressure (MEP).

Upon examining Table 2, the athletes' average and standard deviation values for age, height, weight, years of sports experience, weekly training frequency, and daily training duration are shown.

Upon examining Table 3, it was found that the R^2 values in the regression model for CO_2 production during the $VO_{2max.}$ consumption test showed low predictive power for elite orienteering athletes. According to the model, the predictor variables showed a significant effect on the dependent variable RCP VCO_2 ($F(2,20) = 3.801$; $p = 0.040$). When the significance of the regression weights was examined, it was determined that MEP and MIP variables had a significant influence on changes in the RCP VCO_2 parameter. Regarding VT VCO_2, the predictor variables also had a significant effect on the dependent variable according to the model ($F(2,20) = 6.564$; $p = 0.006$). The significance of the regression coefficients indicated that MEP and MIP variables significantly contributed to variations in the VT VCO_2 parameter among the athletes. However, in the case of Max VCO_2 and $HHVCO_2$, the predictor variables did not demonstrate a significant effect in the model ($F(2,20) = 1.939$; $p = 0.170$ for $MaxVCO_2$; $F(2,20) = 0.098$; $p = 0.907$ for $HHVCO_2$). Analysis of the regression coefficients confirmed that MEP and MIP did not significantly effect changes in $MaxVCO_2$ and $HHVCO_2$ parameters.

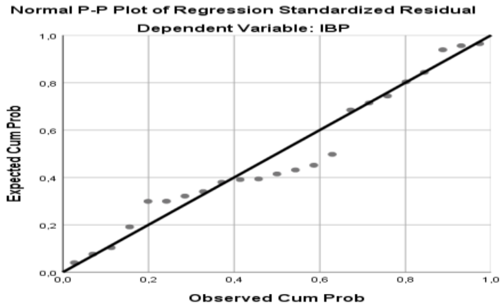
Table 4. Regression Analysis Results of O_2 Consumption Values in Elite Male Orienteering Athletes

	Model	Unstandardized Coefficients		Standardized Coefficients						
		B	Std. Error	Beta	*t*	Sig.	R	R^2	$F_{(2-20)}$	***p***
$RCPVO_2$ (kg/ml/min)	Constant	56.344	6.363		8.855	0	0.448	0.201	2.516	0.106
	MEP (cmH_2O)	-0.064	0.031	-0.044	-2.059	0.053				
	MIP (cmH_2O)	0.093	0.058	0.349	1.614	0.122				
$VT\dot{V}O_2$ (kg/ml/min)	Constant	49.839	6.119		8145	0	0.426	0.181	2.216	0.135
	MEP (cmH_2O)	-0.058	0.03	-0.421	-1.921	0.069				
	MIP (cmH_2O)	0.085	0.056	0.336	1.533	0.141				
VO_2max (kg/ml/min)	Constant	57.178	6.978		8.194	0	0.382	0.146	1.713	0.206
	MEP (cmH_2O)	-0.052	0.034	-0.344	-1.537	0.14				
	MIP (cmH_2O)	0.098	0.064	0.345	1.544	0.138				
İsocapnik Buffering Phase Aera	Constant	-106.058	354.791		-0.299	0.768	0.441	0.194	2.408	0.116
	MEP (cmH_2O)	-0.046	1.736	-0.006	-0.026	0.979				
	MIP (cmH_2O)	6.574	3.229	0.443	2.036	0.055				

Respiratory Compensation Point (RCPVO), Ventilatory Threshold Oxygen Volume ($VT\dot{V}O_2$), Maximal Oxygen Uptake (VO_2max), Maximal Inspiratory Pressure (MIP), Maximal Expiratory Pressure (MEP).

Upon examining Table 4, it was observed that the regression model created to predict oxygen consumption based on the parameters obtained from the maximal VO_2 consumption test—namely $RCPVO_2$, $VT\dot{V}O_2$, VO_{2max}., and the isocapnic buffering phase area—showed low predictive power, as indicated by the low R^2 values. According to the model, the predictor variables had no statistically significant effect on the dependent variable $RCPVO_2$ (F(2,20) = 2.516; p = 0.106). However, an examination of the regression coefficients revealed that the MEP variable had an influence on variations in the $RCPVO_2$ parameter among the athletes. When examining the $VT\dot{V}O_2$ values, the model indicated that the predictor variables did not have a significant effect on the dependent variable (F(2,20) = 2.216; p = 0.135). The significance levels of the regression weights showed that MEP and MIP variables did not significantly contribute to changes in the $VT\dot{V}O_2$ parameter. Similarly, according to the model, the predictor variables did not have a significant effect on VO_{2max} and the isocapnic buffering phase area (F(2,20) = 1.713; p = 0.206; F(2,20) = 2.408; p = 0.116). The regression coefficients indicated that MEP and MIP variables were not effective in explaining the variations in VO_{2max} and isocapnic buffering phase area parameters.

Graph 1. Regression Analysis Results of IBP with MEP-MIP



As it is seen from the graph 1, the regression coefficient has indicated that MEP and MIP variables have not been effective in explaining the variations in VO_{2max} and isocapnic buffering phase area parameters.

Discussion

In the literature, there is evidence suggesting that a longer IBP contributes positively to athletes' aerobic capacity (Oshima et al., 1997; Hirakoba & Yunoki, 2002). However, some studies have argued that the IBP is not significantly related to endurance performance (Bentley et al., 2005). More recent research has indicated that the IBP may serve as a useful predictor of both aerobic and anaerobic capacities in athletes (Hasanli et al., 2015).

On the other hand, it is suggested that high-intensity training increases buffering capacity by enhancing anaerobic metabolism, thereby shifting the RCP to higher intensity levels and consequently extending the IBP duration (Chicharro et al., 2000). Additionally, some studies have shown that aerobic-based training leads to similar improvements in both the VT and the RCP (Chicharro, Hoyos, & Lucia, 2000). When evaluating the findings of our study, the primary objective—examining the relationship between respiratory muscle strength and isocapnic buffering phase parameters—revealed no significant association between respiratory muscle strength and oxygen consumption at VT and RCP. In contrast, Juric et al. (2019) found a significant correlation between MIP and VO_2 consumption at VT in male handball and basketball players. Therefore, our study's findings differ from those of Juric et al. This situation may be attributed to the fact that the athletes in our study enhanced their performance through aerobic-based training combined with interval workouts. In a previous cross-sectional study, the isocapnic buffering range was shown to be more strongly associated with VO_{2max}/wt compared to the VT (Oshima et al., 1997); however, no study has been found in the literature linking respiratory muscle strength with the bicarbonate buffering zone. It can be hypothesized that the elimination of CO_2 produced as a result of metabolic acidosis would increase respiratory muscle workload through hyperventilation, potentially affecting endurance performance. Although our study did not find a significant relationship between the isocapnic buffering area and MIP or MEP, we believe that it may serve as a reference point for researchers studying respiration and respiratory muscle strength. In our study, although the relationship between the isocapnic buffering area and MIP was not statistically significant ($p < 0.055$), we believe that in studies with a larger sample size, inspiratory muscle strength might show tendency as a meaningful factor in the isocapnic buffering phase. It has been demonstrated in the literature that athletes with a history of anaerobic training have higher muscle buffering capacities compared to endurance athletes (Edge et al., 2006). During the IBP, it has been reported that sprint-trained cyclists neutralize accumulated H^+ ions primarily through non-bicarbonate buffering systems, unlike endurance cyclists (Hasanli et al., 2015). We believe this may indicate that the IBP is primarily related to H^+ and bicarbonate systems independently of respiration or that orienteering athletes fall within the endurance athlete profile. Furthermore, we find the inverse tendency of the relationship between $RCPVO_2$ and MEP ($p < 0.053$) observed in our study noteworthy, as it may reflect the potential mechanical or physiological influence of expiratory muscles on this parameter, even though the model itself was not statistically significant. We believe that future studies involving a larger number of athletes, with distinctions made across age and gender, would contribute meaningfully to the literature. In the literature, Klusiewicz (2014) did not find a correlation between MIP and absolute or relative VO_{2max} in male athletes but did find such a correlation in female athletes. Conversely, Deliceoğlu et al. (2024) reported no significant relationship between MIP and MEP values and VO_{2max} in their studies. Our study's findings are consistent with those latter results.

Upon examining the results, it is interpreted that as exercise intensity increases, the carbon dioxide produced by the activation of the bicarbonate buffering system is expelled from the body through an increase in respiratory frequency. However, during periods of elevated respiratory rates, the expiratory muscles may not perform their function efficiently enough within this mechanism. In other words, under high-intensity exercise conditions, it can be inferred that alveolar perfusion may not be adequately distributed across the entire alveolar surface, leading to insufficient time for gas exchange at the alveolar level or possibly indicating the presence of airway obstruction (Stickland et al., 2011; Tedjasaputra et al., 2016). Another finding suggests that stronger respiratory muscles may indicate a more efficient performance, meaning less carbon dioxide is produced for a given workload, reflecting a reduced oxygen demand for the same level of effort. While this specific finding has not been clearly demonstrated in previous studies, it is thought that direct measurements of respiratory muscle oxygen consumption and carbon dioxide production in future research could provide more definitive conclusions.

In conclusion, our study identified significant relationships between the carbon dioxide parameters constituting the isocapnic buffering area and respiratory muscle strength. Considering that carbon dioxide production reflects physiological efficiency, training programs include exercises specifically targeting the diaphragm can be tested.

Limitations of the Study

The limitations of this study include the small sample size, as well as the inability to isolate fatigue parameters due to factors such as gender, age, and the intensity of the competition schedule. Within the scope of the referenced article, the number of our sportmen are limited as there is 20 sportmen who performs at high level (Cipryan et al., 2017). (VO2 maks >55 dk/ml/kg) and upper than five years experience in Turkish Oriantiring Federation as the number of well trained women is not enough, they are not taken into consideration by the Turkish Orientiring Federation.

Financial Resources

This research received no specific grant from any funding agency, commercial or not-for-profit sectors. All financial expenses related to the study were personally covered by the author.

Conflict of Interest

The author declares that there are no conflicts of interest that could have influenced the conduct or outcomes of this research.

Ethics Committee Report

Research data were obtained from athletes who volunteered to participate with the permission of the Orienteering Federation. Ethical approval was obtained from the Gazi University Ethics Committee (Approval No: 2025-540). The study was conducted in accordance with the guidelines of the Declaration of Helsinki. All participants provided written informed consent.

Authors' Contribution

Study Design: TC, GD, BK

Data Collection: BK, TC

Statistical Analysis: GD, TC, YT

Manuscript Preparation: TC, BK

Funding Acquisition: TC

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