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Comparison of young swimmer's active drag coefficient using three methods to compute trunk transverse surface area

Comparação do coeficiente de arrasto activo através de três técnicas de avaliação da área de secção tranversa do tronco em jovens nadadores

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ABSTRACT

The purpose of this study was to compare the active drag coefficient (C_{Da}) of young swimmers using three different ways of measuring the trunk transverse surface area (TTSA). 23 young swimmers, including 12 boys and 11 girls were analyzed. The velocity perturbation method of Kolmogorov was used to compute C_{Da}. The TTSA was calculated based on three methods: i) measured by photogrammetric; ii) estimated by the equation developed by Clarys and; iii) estimated from the equations developed by Morais et al. (2011). Three procedures were used in the comparison C_{Da} values: i) t Student test; ii) simple linear regression analysis and; iii) Bland Altman plots. All paired samples showed significant differences ($p < .001$) when comparing mean values. However, there were significant correlations ($p < .001$) between the paired samples in the simple linear regression analysis, and the in the Bland Altman plots for all conditions studied. At least 80% of the plots were within the ± 1.96 standard deviation of the difference. As a conclusion, the mean values of C_{Da} computed with TTSA estimated with the equations developed by Morais et al. (2011) were the ones with lower difference compared with TTSA measured directly. Those should be used by coaches and investigators in order to estimate TTSA for C_{Da} computing.
Keywords: swimming, hydroninamics, anthropometrics, drag

RESUMO

Foi objectivo deste estudo comparar o coeficiente de arrasto activo, calculado com recurso a três formas distintas de medição da área de secção transversa do tronco (ASTT). A amostra foi composta por 23 sujeitos, entre os quais 12 do sexo masculino e 11 do sexo feminino. Foi utilizado o método de perturbação de velocidade de Kolmogorov para calcular o arrasto activo e respectivo coeficiente de arrasto. O cálculo do coeficiente de arrasto foi efectuado de três formas distintas: i) com recurso à ASTT medida através de fotogrametria; ii) com recurso ASTT estimada a partir das equações de Morais et al. (2011); e iii) com recurso à ASTT estimada através da equação de Clarys. Foram utilizados três procedimentos no processo de comparação: i) comparação de valores médios; ii) análise de regressão linear simples; e iii) plot de Bland Altman. Todos os pares estudados apresentaram diferenças significativas ($p < .001$) na comparação de valores médios. No entanto, as análises de regressão lineares simples entre os pares estudados, registaram correlações significativas ($p < .001$), e o plot de Bland Altman, para todas as condições estudadas, registou mais de 80% dos plots dentro do intervalo de confiança de 95 %. Constatou-se que as equações de Morais et al. foram aquelas que apresentaram menor diferença (13.81 ± 9.24%), comparativamente com a de Clarys (26.87 ± 5.61%) em relação aos valores de ASTT medidos. Sugere-se assim a aplicação destas equações para a estimação da ASTT.
Palavras-chave: natação, hidrodinâmica, antropometria, arrasto

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Hydrodynamic drag represents the force that a swimmer has to overcome in order to maintain his movement through water. This force is dependent on velocity, shape, size, frontal surface area and it is similar to the general pressure drag equation (Kjendlie & Stallman, 2008):

$$D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot S \cdot C_d \quad (1)$$

where D is the drag force [N], ρ is the density of the water [kg·m^{-3}], v is the swimming velocity [m·s^{-1}], S is the projected frontal surface area of the swimmers [cm^2] and Cd is the drag coefficient.

On a regular basis, the drag force can be measured based on two conditions (Marinho et al., 2009; Pendergast et al., 2006): i) with the swimmers towing in water without segmental actions (i.e. passive drag); or ii) while the subject is making segmental actions to propeller him/herself (i.e. active drag). For passive drag measurement, subjects are passively towed on prone and hydrodynamic position holding a wire in the hands (Zamparo, Gatta, Pendergast, & Capelli, 2009). For the active drag measurement several experimental methods, such as, the drag-system apparatus (Hollander et al., 1986) and the velocity perturbation method (VPM) (Kolmogorov & Duplischeva, 1992) or numerical methods, such as, computed fluid dynamics (CFD) (Marinho et al., 2009) can be applied. Some of those need to include in the data input the individual trunk transverse surface area (TTSA). Although, the TTSA can be directly measured in each subject by the photogrammetric techniques (Morais et al., 2011), its collection and treatment are somewhat time consuming and/or expensive.

To avoid this issue, several authors developed equations to estimate the TTSA based on anthropometrical variables. Clarys (1979) suggested a TTSA estimation equation based on the subject's body mass and height (R^2 = .50):

$$TTSA = 6.9256\, BM + 3.5043\, H - 377.156 \quad (2)$$

where TTSA is the trunk transverse surface area [cm^2], BM is the body mass [kg] and H is the height [cm].

This last one was developed using stepwise regression models that included several anthropometrical variables of 63 physical education students and nine Olympic swimmers. However, Marinho et al. (2010) reported that Equation 2 has some limitations: (i) the sample was reduced and only nine subjects were from Olympic level; (ii) the anthropometrical characteristics of the swimmers of the 70's are not the same as the ones of the XXI century and; (iii) on a regular basis is used to assess drag force in children (Barbosa, Costa, Marques, Silva, & Marinho, 2010), male and female subjects (Kolmogorv, Lyapin, Rumyantseva, & Vilas-Boas, 2000; Toussaint, Roos, & Kolmogorov, 2004) without a clear knowledge of the good-of-fit of the model to different cohort groups.

Considering this purpose, Morais et al. (2011) developed new equations for TTSA estimation in males and females swimmers, respectively:

$$TTSA = 6.662 \cdot CP + 17.019 \cdot CSD - 210.708 \quad (3)$$

$$TTSA = 7.002 \cdot CP + 15.382 \cdot CSD - 255.70 \quad (4)$$

where $TTSA$ is the trunk transverse surface area in cm^2, CP is the chest perimeter in cm and CSD is the chest sagital perimeter in cm.

One important practical consideration for swimming researchers and coaches is to know if there are differences in the drag coefficient values depending on the technique used to calculate TTSA.

Thus, the purpose of this study was to compare the drag coefficient using the three different methods to calculate TTSA: i) by photogrammetric technique; ii) estimated with Equation 2; and iii) estimated with Equations 3 and 4.

METHODS

Participants

Twenty-three young swimmers (twelve boys and eleven girls) participating on regular basis in regional and national level competitions volunteered as subjects (boys: 14.42 ± 1.24 years old, 1.66 ± .09 m of height, 56.45 ± 10.80 kg of body mass, 3.33 ± .78 on Tanner stages by self-evaluation; girls: 12.73 ± .79 years old, 1.60 ± .05 m of height, 47.55 ± 6.27 kg of body mass, 3.00 ± .89 on Tanner stages by self-evaluation). Coaches and parents gave their consent for the swimmers participation on this study and all procedures were in accordance to the Declaration of Helsinki in respect to Human research. The Institutional Review Board of the Polytechnic Institute of Bragança approved the study design.

Instruments and Procedure

TTSA data collection

The TTSA was measured using three methods. It was measured directly, with the subjects being photographed with a digital camera (DSC-T7, Sony, Tokyo, Japan) in the transverse plane from above (Caspersen, Berthelsen, Eik, Pâkozdi, & Kjendlie, 2010). Subjects were on land, in the upright and hydrodynamic position. This position is characterized by the arms being fully extended above the head, one hand above the other, fingers also extended close together and head in neutral position. Subjects wore a regular textile swimsuit, a cap and goggles. Besides the subjects, on the camera shooting field there was a calibration frame with .945 m length at the height of the xiphoid process (Morais et al., 2011). TTSA was measured from the subject's digital photo with specific software (Udruler, AVPSoft, USA). Procedures included: i) scale calibration; ii) manual digitalization of the transverse trunk perimeter; and iii) output and recording of the TTSA value.

Trunk transverse surface area was also was measured using estimation equations. To estimate TTSA using Equation 2, the body mass was measured in the upright position with a digital scale (SECA, 884, Hamburg, Germany) and body height was measured in the anthropometrical position from vertex to the floor with a digital stadiometer (SECA, 242, Hamburg, Germany). To estimate TTSA using Equations 3 and 4, the chest perimeter and the chest sagital diameter were measured (Morais et al., 2011). The chest perimeter is defined as the perimeter of the trunk at the level of the xiphoid process, was measured with a flexible anthropometrical tape (Metric Tape, RossCraft, Canada) with the subject in the upright and hydrodynamic position. The chest sagital diameter is considered as the distance between the back and the highest point of the chest (i.e. antero-posterior) at the level of the xiphoid process and was also measured with a specific sliding caliper (Measuring Clip, RossCraft, Canada).

Active drag and active drag coefficient calculation

These hydrodynamic variables were computed using the velocity perturbation method with the help of an additional hydrodynamic body used to determine active drag in Front Crawl swimming (Kolmogorov & Duplishcheva, 1992; Kolmogorov, Rumyantseva, Gordon, & Cappaert, 1997). Active drag was calculated from the difference between the swimming velocities with and without towing the perturbation buoy. To ensure similar maximal power output for the two sprints, the swimmers were instructed to perform maximally at both 25 m trials. Between bouts swimmers had a passive rest of at least 30 minutes. Each swimmer performed two maximal 25 m at Front Crawl with an underwater start with and without the perturbation device. Subjects performed the bouts alone without any other swimmer in the same swim lane and in the nearby lanes to reduce drafting, pacing effects and bias in the drag force. Swimming velocity was assessed during 13 m (between 11 m and 24 m from the starting wall). The time spent to cover this distance was measured with a manual chronometer (Golfinho Sports MC 815, Aveiro, Portugal) by two expert evaluators and mean value was used for further analysis (Marinho et al., 2010). Active drag (D_a) was calculated as (Kolmogorov & Duplisheva, 1992):

$$D_a = \frac{D_b v_b v^2}{v^3 - v_b^3} \quad (5)$$

where D_a represents the swimmer's active drag at maximal velocity in N, D_b is the resistance of the perturbation buoy in N and, v_b and v are the swimming velocities with and without the perturbation device in m·s^{-1}, respectively.

The drag of the perturbation buoy was calculated from the manufacturer's calibration of the buoy-drag characteristics and its velocity (Kolmogorov & Duplisheva, 1992). Active Drag coefficient (C_{Da}) was calculated as:

$$C_{Da} = \frac{2 \cdot D_a}{\rho \cdot S \cdot v^2} \quad (6)$$

where ρ is the density of the water (assuming to be 1000 kg/m^3), Da is the swimmer's active drag in N, v is the swimmer's velocity in m·s^{-1} and S is the projected frontal surface area of the swimmers in cm^2 and it was computed using the three methods mentioned above.

Statistical Analysis

The normality and homocedasticity assumptions were checked respectively with the Kolmogorov-Smirnov and the Levene tests. Descriptive statistics (mean, one standard deviation, minimum and maximum) from all measured variables were calculated. The comparison between active drag coefficients was made by: i) comparing mean data; ii) computing simple linear regression; and iii) computing Bland Altman plots. Comparison between the mean values of active drag coefficient was made using paired Student's t test ($p \leq .05$). Simple linear regression model between values of active drag coefficient was computed. As a rule of thumb, for qualitative and effect size analysis, it was defined that the relationship was: i) very weak if $R^2 < .04$; weak if $.04 \leq R^2 < .16$; moderate if $.16 \leq R^2 < .49$; high if $.49 \leq R^2 < .81$ and; very high of $.81 \leq R^2 < 1.0$. In addition, the error of estimation (s) and the confidence interval for 95 % of the adjustment line in the scatter gram was computed. The Bland Altman analysis (Bland & Altman, 1986) included the plot of the mean value of active drag coefficient computed versus the delta value (i.e. difference) between them. It was adopted as limits of agreement a bias of ± 1.96 standard deviation of the difference (average difference ± 1.96 standard deviation of the difference). For qualitative assessment, it was considered that the comparison was valid and appropriate if at least 80% of the plots were within the ± 1.96 standard deviation of the difference.

RESULTS

Table 1 presents the descriptive statistics for all selected anthropometrical variables. The mean value of the TTSA measured directly was 778.34 ± 150.75 cm^2 and estimated according to Equation 2 and Equations 3 and 4 were 557.16 ± 94.83 cm^2 and 692.91 ± 101.10 cm^2, respectively.

Table 2 presents the descriptive statistics for values of C_{Da} based on the three methods to compute TTSA. The mean values of C_{Da} computed with TTSA measured directly, estimated with Equation 2 and with Equations 3 and 4 were .244, .333 and .288 respectively.

Figure 1 presents the comparison of mean data, scatter gram and Bland Altman plots for C_{Da} computed with three different methods of measuring TTSA, respectively. There were significant differences in C_{Da} mean data comparison between the three methods to compute TTSA ($p < .05$). The simple linear regression presented high and significant determination coefficients. Between the mean value of C_{Da} measured with TTSA computed directly and TTSA estimated with Equation 2 ($R^2 = .958$), between the mean value of C_{Da} measured with TTSA computed directly and TTSA estimated with Equations 3 and 4

Table 1

Anthropometrical characteristics of all subjects for body mass (BM), body height (H), chest sagital diameter (CSD), chest perimeter (CP) and trunk transverse surface area (TTSA)

	BM [kg]	H [cm]	CSD [cm]	CP [cm]	TTSA measured [cm^2]	TTSA estimated (Equation 2) [cm^2]	TTSA estimated (Equations 3 and 4) [cm^2]
Mean	52.19	163.47	20.47	81.17	778.34	557.16	692.91
1 *SD*	9.84	8.30	2.10	6.76	150.75	94.83	101.10
Minimum	39.8	149.3	16.9	71	604.1	421.6	557.2
Maximum	73.2	179.5	26.6	100	1243.6	758.8	986.2

Table 2

Descriptive statistics for active drag coefficient (C_{Da}) measured with three methods to compute TTSA

	C_{Da} measured [dimensionless]	C_{Da} estimated (Equation 2) [dimensionless]	C_{Da} estimated (Equations 3 and 4) [dimensionless]
Mean	.244	.333	.288
1 *SD*	.097	.131	.133
Minimum	.140	.194	.151
Maximum	.574	.815	.793

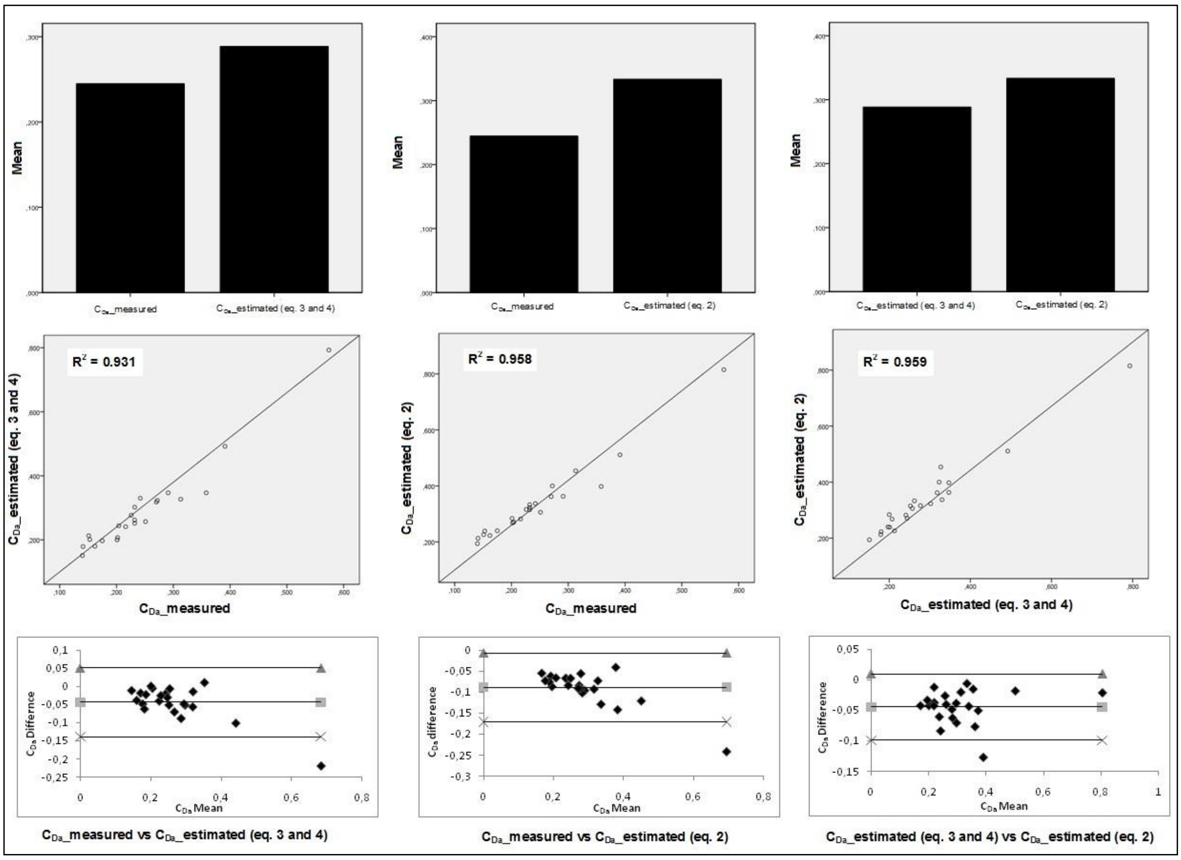

Figure 2. Comparison of mean data, scatter gram and Bland Altman plots for active drag coefficient measured with three different methods to compute trunk transverse surface area

(R^2 = .931), and between the mean value of C_{Da} measured with TTSA estimated with Equation 2 and with Equations 3 and 4 (R^2 = .959). For the Bland Altman analysis, in all three methods to compute C_{Da} the cut-off value of at least 80% of the plots within ± 1.96 *SD* was accomplished.

The C_{Da} mean value computed with the variable TTSA measured directly was 26.87 ± 5.61% lower than the one computed with TTSA estimated with Equation 2, and 13.80 ± 9.24% lower than the one computed with TTSA estimated with Equations 3 and 4. The difference between the C_{Da} mean value measured with TTSA estimated with Equation 2 was 14.56 ± 7.86% lower in comparison with the one computed with TTSA estimated with Equations 3 and 4. The simple linear regression between the C_{Da} measured based in the three established methods to compute TTSA presented high and significant determination coefficients.

DISCUSSION

The purpose of this study was to compare the drag coefficient based on three different methods to measure TTSA: i) by photogrammetric technique; ii) estimated with Equation 2; and iii) estimated with Equations 3 and 4. Main results were that the C_{Da} computed with TTSA estimated with Equations 3 and 4 was the one that presented a lower delta value to the C_{Da} computed with TTSA measured directly.

Mean data values of C_{Da} and TTSA are within the range of those reported in the literature for swimmers with similar gender, chronological and biological ages for the selected variables evaluated (Barbosa et al., 2010; Marinho et al., 2010). The measuring of TTSA, that is a variable needed to compute the active drag coefficient, can be made directly or estimated by equations. The Equation 2, developed of Clarys (1979), has commonly been used to estimate TTSA. In a study made by Barbosa et al. (2010) the variable TTSA estimated with such equation was excluded by a path-analysis model leaving the authors to suggest new estimate equations to compute TTSA. In the study of Morais et al. (2011) new equations by gender were developed to estimate TTSA. This paper made a comparison of the C_{Da} based in these three methods to compute TTSA. These results present that C_{Da} mean values computed with TTSA estimated with Equations 3 and 4 are more similar to C_{Da} mean values computed with TTSA measured directly. So it might be suggested that these equations are more reliable to estimate TTSA.

Three procedures were used to compute the comparison between C_{Da} (Baldari et al., 2009; Kristensen, Bandholm, Holm, Ekdahl, & Kehlet, 2009; Wolfram, Wilke, & Zysset, 2010). In the t-test comparison there were significant differences ($p \leq 0.05$) between all C_{Da} mean data. The simple linear regression presented high and significant determination coefficients between active drag coefficient value measured with all three methods to compute TTSA. In the Bland Altman analysis (Bland & Altman, 1986) at least 80% of the plots were within ± 1.96 *SD* in all three methods of C_{Da} computing. So, from the selected three criteria, two of them were accepted to validate the Cd measurement with different TTSA measuring/estimating procedures. One possible reason for the mean values t-test comparison was not accomplished might be the low scale of C_{Da} mean values.

It can be considered as main limitations of the study: i) the equations developed by Morais et al. (2011) can only be applied to subjects with that specific range of ages; and ii) when computing C_{Da} based on TTSA estimated with such equations it must be computed an underestimate of 13.80%.

CONCLUSIONS

As a conclusion: i) C_{Da} values were similar when measured with three different methods to compute TTSA; and ii) the measurement of C_{Da} with TTSA estimated with Equations 3 and 4 had the lowest delta value to those with TTSA computed directly. In that case, we can state that these equations are more reliable when estimating TTSA than Equation 2.

As a coach friendly conclusion it can be suggested that Equations 3 and 4 are those that should used by coaches and investigators in order to estimate TTSA for C_{Da} computing.

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