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Title: Which method should be chosen to estimate the oxygen cost of walking in post-stroke individuals?

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Running Head: estimating oxygen cost of walking in stroke

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Which method should be chosen to estimate the oxygen cost of walking in post-stroke individuals?

Abstract:

Background: The oxygen cost of walking (C_w) represents the energy expenditure involved in walking, which is a major concern when quantifying physical activity in stroke. Recent studies have reported that C_w may be estimated accurately with a prediction equation using the self-selected walking speed (S_{free}).

Research question: to evaluate the validity of C_w estimates according to different modalities of S_{free} measurements (10-m walking test, 6-minute walking test, GaitRite system).

Methods: twenty-one stroke individuals in subacute phase who were able to walk without human aid were included. C_w was estimated from the walking speed measured during a 10-m walking test, a 6-minute walking test and a recording on a GaitRite system. The values of the C_w estimates were compared to those measured by a respiratory gas exchange analyzer (Metamax3b).

Results: the findings showed that there is no significant difference between the C_w measured by Metamax3b and the C_w estimates regardless of the modalities used to measure S_{free} (Fvalue= 0.02; pvalue = 0.99). The mean bias between C_w measured by the Metamax3b and those estimated using the different S_{free} measurement modalities was less than 2.5% of the mean C_w value. Test retest reliability was excellent with an intraclass correlation coefficient higher than 0.95.

Significance: in stroke survivors who are able to walk independently without human aid, the use of a 10-m walking test, a 6-minute walking test or a GaitRite recording can be considered validated for estimating C_w .

Key words: stroke; gait; energy cost; energy expenditure; oxygen cost

The oxygen cost of walking (C_w) represents energy demand while walking[1]. C_w in post-stroke individuals is, on average, 1.5 to 2 times that of healthy individuals at equivalent speeds. It varies considerably from one person to another based on the type and severity of impairment [2]. Recent studies have illustrated that C_w could be accurately assessed based on a prediction equation using walking speed at a self-selected comfort pace (S_{free})[3,4]. The C_w estimates make it possible to quantify energy expenditure while walking without using constraining devices such as respiratory gas exchange analyzers.

In the C_w prediction equation used by Compagnat et al, S_{free} was measured with a 6-minute walking test (6MWT), which may lead to difficulties in implementation when monitoring outpatients. Classically, S_{free} is measured during a 10-m walking test (10MWT) or measured instrumentally, for example by a GaitRite mat. Measurement time can be shorter with these methods, improving the feasibility of the C_w assessment[5]. It is necessary to evaluate whether the use of another modality to measure S_{free} is valid because the relationship between C_w and S_{free} in the prediction equation used by Compagnat et al. is not linear, a small variation in S_{free} can generate a very large variation in C_w [3].

The main purpose was to evaluate the validity of C_w estimations based on different S_{free} measurement methods (6MWT, 10MWT, GaitRite). The 2nd purpose was to assess the test-retest reliability of the C_w estimations based on the S_{free} methods used.

We included 21 individuals who had suffered a hemisphere-localized stroke in subacute phase. These individuals had to be able to move for six minutes without human aid. A clinical assessment of stroke individuals was performed to characterize the level of impairment and functional independence of the participants included. We recorded S_{free} using three methods at 2 different assessment times (D0 and D1) spaced 1 to 4 days apart. S_{free} was assessed using a 6MWT over obstacle-free flat ground without turning around; a 10MWT along a corridor; and a 7-meter GaitRite system. We used the S_{free} values to estimate C_w based on the method described by Compagnat et al., 2018, using the prediction equation: $C_w=0.2109*S_{free}^{-0.877}$ [3]. To ensure the validity of the estimations, we compared the estimated C_w values with a value measured using a portable respiratory gas exchange analyzer

(Metamax3b)[6]. The research protocol was accepted by an ethics committee, notice number 480-2021-136.

The agreement analysis for the different Cw estimation methods used, and the test-retest evaluations, was performed using Bland-Altman analysis (mean bias (MB), limits of agreement (LoA))[7] and 2-way ANOVA (first way: Metamax3b, 10MWT, 6MWT, GaitRite, and second way: D0, D1), and intra-class correlation coefficients (ICC). All the statistical analyses were made using R version 3.6.3 Copyright 2020, packages “BlandR” and “base”.

The post-stroke individuals were 65.6 ± 12.7 years old. They had a post-stroke delay of 39 days (IQR=255), a median value of 74 (IQR=23) in Demeurisse Motricity Index, 6/8 (IQR=3) in modified Functional Ambulation Classification and 83/100 (IQR=25) in Barthel Index. Six out of 22 had an assistive device during ambulation. We did not find any significant statistical difference between the S_{free} values measured according to the different modalities ($S_{\text{free 10MWT}} = 0.83 \pm 0.33 \text{ m.s}^{-1}$, $S_{\text{free 6MWT}} = 0.82 \pm 0.30 \text{ m.s}^{-1}$ or $S_{\text{free GaitRite}} = 0.85 \pm 0.33 \text{ m.s}^{-1}$; $F=0.06$; $p\text{-value} = 0.45$).

Bland Altman's analysis comparing the Cw values measured by Metamax3b and those estimated using S_{free} , according to the different S_{free} measurement methods, reported MB lower than $0.007 \text{ mL.kg}^{-1} \cdot \text{m}^{-1}$ (<2.5% of mean value) and LoA lower than $0.10 \text{ mL.kg}^{-1} \cdot \text{m}^{-1}$ (<40% of mean value). (Figure 1; additional Table T1)

Emplacement for Figure 1

The 2-way ANOVA analysis (first way: Metamax3b, 10MWT, 6MWT, GaitRite, and second way: D0, D1) did not show any significant effect on Cw values ($F=0.02$; $p\text{-value}=0.99$). The Bland Altman analysis between Cw values at D0 and D1 reported MB lower than 5% and LoA lower than 35% D1 (Figure 1; Additional Table T1). In addition, ICC exceeded 95% for all Cw estimation methods used between D0 and D1 (Additional Table T2).

Our work reports very good agreement with the gold standard ($MB < 0.007 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{m}^{-1}$ (<2.5% of mean value) and $LoA < 0.10 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{m}^{-1}$ (<40% of mean value)) and test-retest reliability ($ICC > 0.95$) for the C_w estimation, irrespective of the S_{free} measurement methods used.

This absence of significant difference between the different methods used for estimating C_w can be explained by the fact that there was no difference in the S_{free} assessment (10MWT, 6MWT, and GaitRite system). This result is in line with the results provided by Dobkin et al., 2006[8]. Through a group of 24 post-stroke individuals, the authors showed that there was no significant difference between S_{free} measured over a short distance (15m) and that measured over six minutes (mean difference= 0.00 ± 0.05 ; $p=0.30$)[8]. The lack of difference between S_{free} values was important because a small variation in the value of S_{free} can lead to a very large variation in the C_w estimate due to the asymptotic relationship between S_{free} and C_w in the prediction equation used by Compagnat et al. [3].

Our work also demonstrated the very good test-retest reliability for the C_w estimation based on the method described by Compagnat et al., 2018 (MB lower than 5%, $ICC > 0.9$). This quality is important because it is vital to ensure that there are no errors when measurements are taken repeatedly in everyday clinical practice.

These results encourage the use of this method for estimating C_w in post-stroke individuals. It would be more appropriate to recommend using the 10-meter S_{free} measurement as it is the easiest and most commonly used measurement method in clinical practice[9]. Furthermore, if walking is measured instrumentally using a GaitRite mat, our results show that the speed value can be extracted to estimate C_w .

C_w can be used to estimate the energy expended by post-stroke individuals when walking. This in turn can be used to propose personalized walking activity recommendations to attain the recommended 1000kcal/week during physical activities. The advantage of this type of recommendation is that it takes into account inter-individual C_w variability and proposes person-specific walking objectives[3]. Moreover, C_w can be used with a portable physical activity monitor to convert the walking distances recorded by these monitors into energy expenditure in order to assess

the level of physical activity attained by an individual[11]. To date, it is the only method integrating inter-individual C_w variability when assessing the level of physical activity [12].

One of the limitations of our study is the small sample and the high levels of walking ability among the participants in the study. It will be important to perform an additional study on a larger cohort of patients and on individuals with lower walking speeds. Another limitation is that we only included individuals who had suffered from hemispheric strokes. This type of method can, therefore, only be used for these individuals, which limits its application.

In conclusion, with this study we illustrate the possibility of using any S_{free} measurement method in stroke patients for estimating C_w based on the method described by Compagnat et al. We also show a very good level of test-retest reliability irrespective of the S_{free} measurement method used. These results encourage the use of this method of estimating C_w in clinical practice in individuals with stroke.

The authors have no conflicts of interest to declare.

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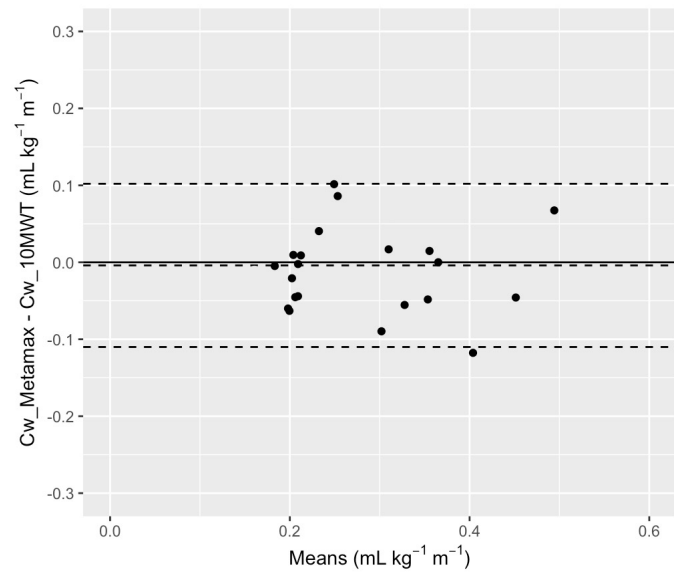
Tables and Figures legends

Figure 1: Bland Altman plots comparing Cw values according to different measurement and estimation modalities, as well as during test-retest evaluation (D0: first exploration and D1: second exploration; Cw: oxygen cost of walking; 10MWT: 10-meter walking test; 6MWT: 6-minute walking test)

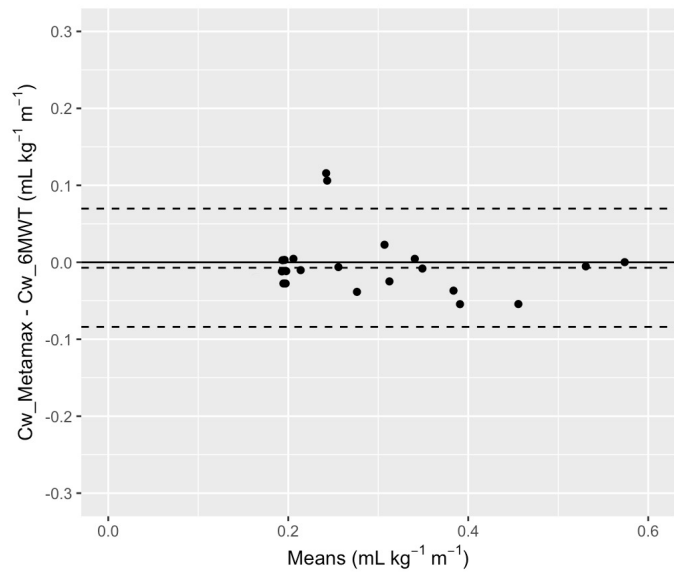
Additional Table T1: values of the oxygen cost-of-walking estimates according to the walking speed measurement method and variations during the test-retest evaluation. D0: first exploration; D1: second exploration; ICC: intraclass correlation coefficient; IC95%: interval confidence at 95%; Cw: oxygen cost of walking; 10MWT: 10-meter walking test; 6MWT: 6-minute walking test

Additional Table T2: values of the Cw estimates according to the walking speed measurement method during the test-retest evaluation. D0 : first exploration ; D1 : second exploration ; ICC : intraclass correlation coefficient ; IC95% : interval confidence at 95% ; Cw : oxygen cost of walking ; 10MWT : 10-meter walking test ; 6MWT : 6-minute walking test

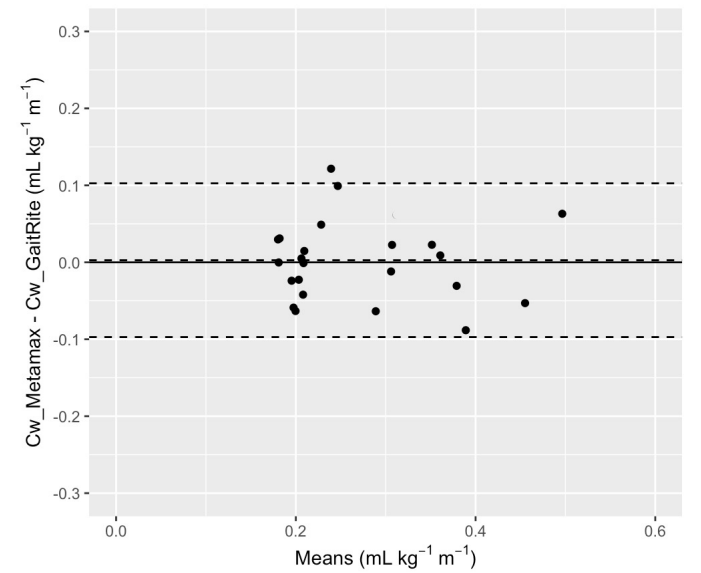
Comparison Cw_Metamax and Cw_10MWT



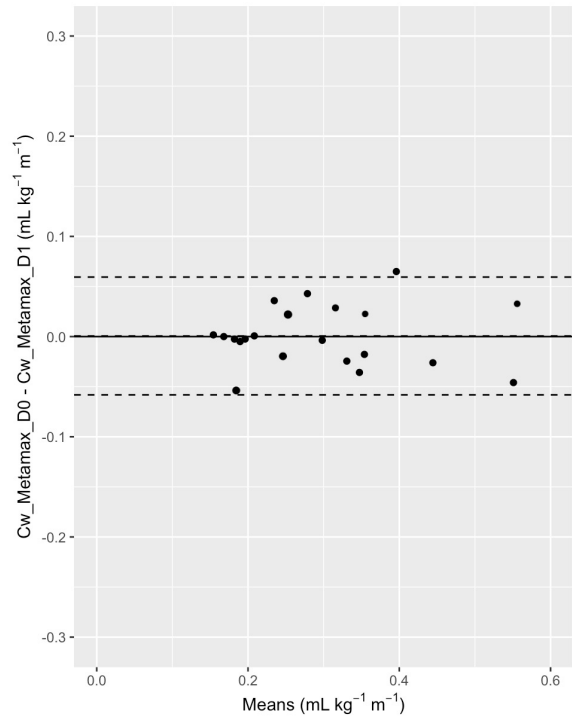
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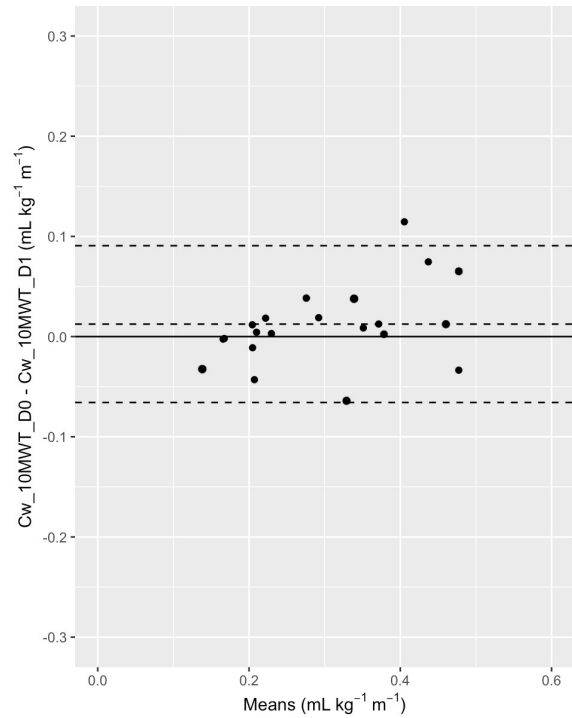
Comparison Cw_Metamax and Cw_GaitRite



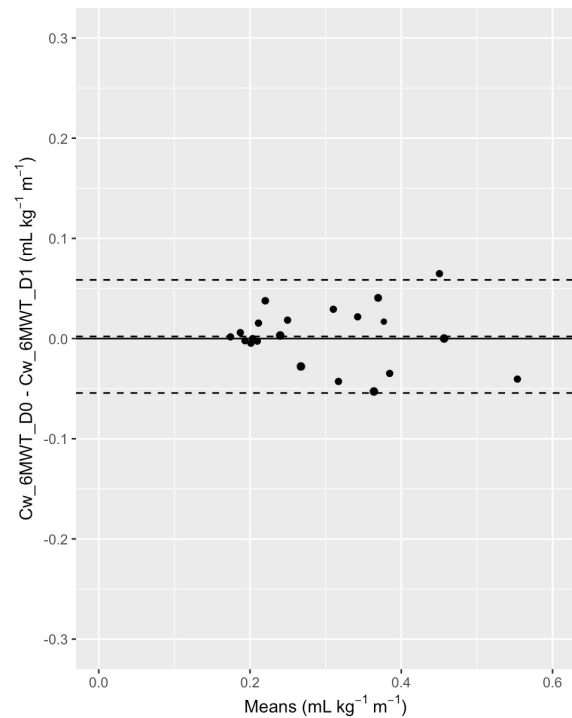
Comparison D0 vs D1 for Cw_Metamax



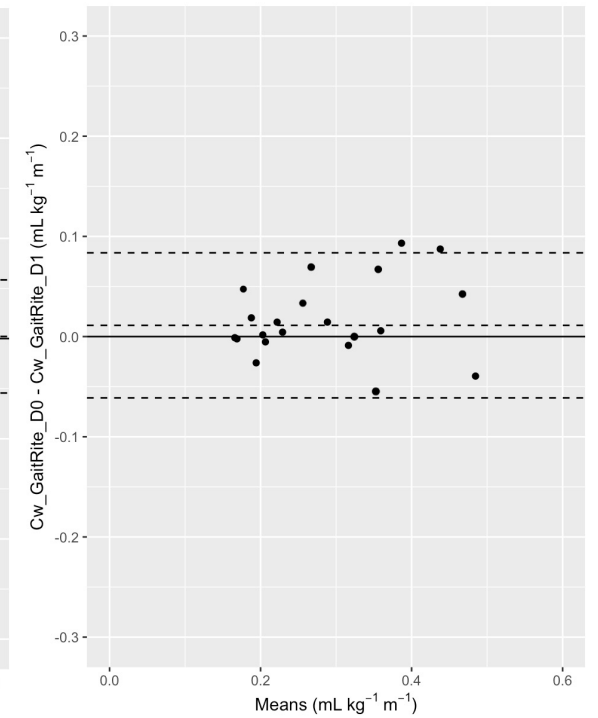
Comparison D0 vs D1 for Cw_10MWT



Comparison D0 vs D1 for Cw_6MWT



Comparison D0 vs D1 for Cw_GaitRite



Additional table T1 : Bland Altman analyses

Variables analyzed	MB	% MB	Up LOA	%Up LOA	Lo LOA	%Lo LOA	2 way ANOVA
Cw_Metamax vs Cw_10 MWT	-0.004	- 1.46%	0.10	36.73%	-0.11	-39.65%	F = 0.02 p = 0.99
Cw_Metamax vs Cw_6M WT	-0.007	- 2.56%	0.07	25.12%	-0.08	-30.23%	
Cw_Metamax vs Cw_Gait Rite	0.003	0.99%	0.10	36.96%	-0.10	-34.98%	
D0 vs D1 for Cw_10MWT	0.012	4.49%	0.09	32.67%	-0.07	-23.69%	
D0 vs D1 for Cw_6MWT	0.002	0.77%	0.06	21.10%	-0.05	-19.56%	
D0 vs D1 for Cw_GaitRite	0.011	4.04%	0.08	30.11%	-0.06	-22.04%	
D0 vs D1 for Cw_Metamax	0.001	0.22%	0.06	21.39%	-0.06	-20.95%	

Cw : oxygen cost of walking ; MB : mean bias in mL.kg⁻¹.m⁻¹ ; %MB : mean bias expressed in percentage of Cw mean values measured by Metamax ; Up LOA : Upper limits of agreement ; Lo LOA : lower limits of agreement ; %Up LOA = upper limits of agreement expressed in percentage of Cw mean values measured by Metamax ; %Lo LOA = lower limits of agreement expressed in percentage of Cw mean values measured by Metamax ; 10MWT : 10 meters test ; 6MWT : 6 minutes of walking ; D0 = initial evaluation ; D1 = second valuation

Additional Table T2: values of the Cw estimates according to the walking speed measurement method during the test retest evaluation.

	D0		D1		ICC (D0 vs D1)	
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>value</i>	<i>IC95%</i>
Cw Metamax	0.28	0.11	0.28	0.12	0.97	(0.91 - 0.99)
Cw GaitRite	0.28	0.11	0.27	0.10	0.96	(0.89 - 0.99)
Cw 10MWT	0.29	0.12	0.28	0.10	0.97	(0.92 - 0.99)
Cw 6MWT	0.29	0.11	0.28	0.12	0.96	(0.90 - 0.99)

D0 : first exploration ; D1 : second exploration ; ICC : intraclass correlation coefficient ;
 IC95% : interval confidence at 95% ; Cw : oxygen cost of walking ; 10MWT : 10 meters walking test ; 6MWT : 6 minutes of walking